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FANO RESONANCES

Omnipresence of Fano resonances in nanophotonics

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Keywords : Nanophotonics, Mie scattering, optical nanoantennas

Fano resonance is a universal phenomenon, which can be observed in any system supporting wave interference of arbitrary nature. We'll give an overview of application of the Fano resonance in nanophotonics, including light propagation in photonic crystals, scattering by array and individual nanoparticles.

The physics of Fano resonance is widely known across many different branches of physics[1]. It manifests itself as a sharp asymmetric profile of the transmission or absorption lines, and it is observed in numerous physical systems, including light absorption by atomic systems, Aharonov-Bohm interferometer and quantum dots, resonant light propagation through photonic-crystal waveguides, and phonon scattering by time-periodic scattering potentials. From the viewpoint of the fundamental physics, the Fano resonance may appear in the systems characterized by a certain discrete energy state that interacts with the continuum spectrum through an *interference effect*. Usually, the discrete state is created by a defect that allows one (or several) additional propagation paths in the wave scattering which interact constructively or destructively. In the transmission line, this interference effect leads to either *perfect transmission* or *perfect reflection*, producing a sharp asymmetric profile.

The smart use of light in science and technology is at the core of an impressive number of high-performance photonic devices ranging from laser chips and optical sensors, to all-optical communication systems for high-speed computing and data transfer[2]. Such functionality is achieved due to an extensive use of optical microcavities in various geometries involving coupling of one or several cavities to a waveguide. A powerful principle that could be explored to implement all-optical transistors, switches, and logical gates is based on the concept of optical bistability. Several theoretical and experimental studies explored *nonlinear Fano resonances* for the design of optimal bistable switching in nonlinear photonic crystals[3]. A photonic crystal provides an optimal control over the input and output, and facilitates further large-scale optical integration.

One of the simplest bistable optical devices is a nonlinear two-port structure which is connected to other parts of a circuit by one input and one output waveguides. Its

scattering properties depend on the light coupled to the input waveguide. One of the realizations of such a device is provided by a waveguide side-coupled to an optical cavity. This system is known to exhibit a Fano resonance with a sharp suppression of the transmission and enhanced reflection[4].

This concept was recently extended to a finite clusters of silicon nanoparticles, which support Fano resonance[5], which originates from the optically induced magnetic dipole modes of individual high-dielectric nanoparticles. It is also associated with the possibility to create nonradiating current distributions in a finite volume[6].

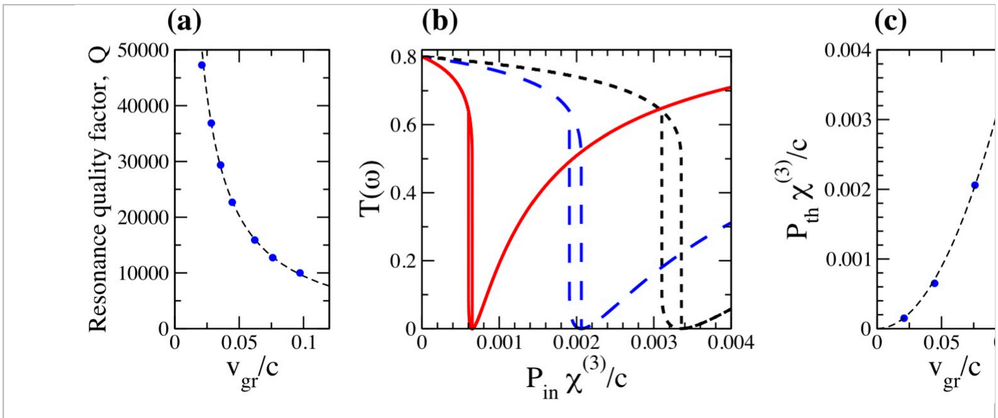

Figure 1: Ultra-low all-optical switching in the slow-light regime. (a) Quality factor Q vs. group velocity vg at resonance for the waveguide-cavity structure. (b) Nonlinear bistable transmission at the frequencies with 80% of linear light transmission vs. the incoming light power for different values of the rod radius; (c) Switch-off bistability threshold vs. the group velocity at resonance.

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Explaining the x-ray nonlinear susceptibility of diamond and silicon obtained from the Fano effect near absorption edges.

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Keywords: Parametric down conversion – non-linear x-ray optics – Fano line-shape

The x-ray parametric down-conversion (PDC) interferes with the x-ray inelastic scattering by producing Fano line-shapes [1,2] shown in Fig. 1.

By analyzing these results, one can estimate the magnitude of the nonlinear susceptibility

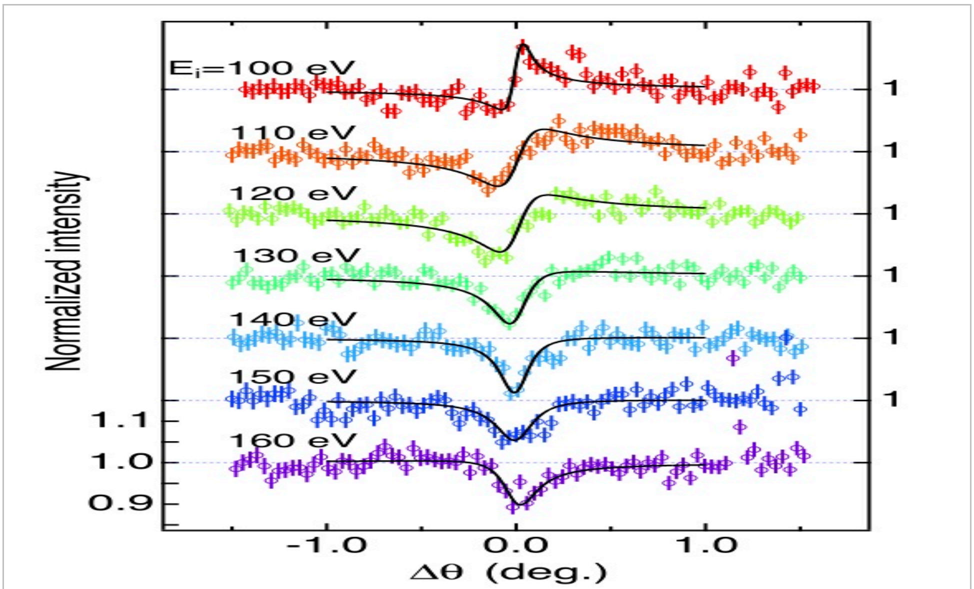

Figure 1: Rocking curves of the 111 nonlinear diffraction of a Si crystal. Circles with error bars represent the measurements and full lines are fits to the data with the Fano formula used by Tamasaku, Sawada, and Ishikawa [3].

[3]. The value obtained increases significantly at the K absorption edge of diamond and at the L_{23} absorption edge of a silicon crystal. Using arguments similar to those invoked to successfully predict resonant inelastic x-ray spectra [4], one can derive an expression for the renormalization term of the non-linear susceptibility at the x-ray edges, which can be

evaluated by using first-principles calculations of the atomic scattering factor f_1 as shown in Fig. 2 and explained in Ref. [5].

Our first principles calculations of f_1 based on the program FDMNES (standing for finite

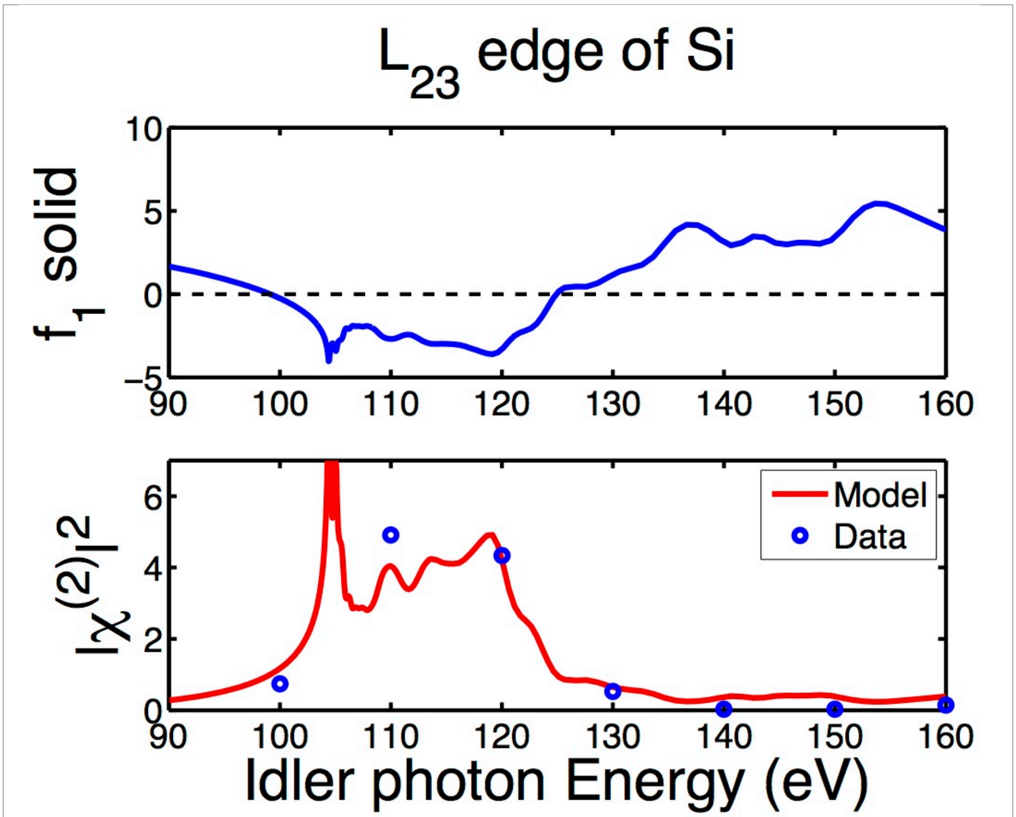

Figure 2: L_{23} edge of silicon: In the top frame the solid curve represents the model for f_1 as a function of the idler energy. The label "f_1 solid" emphasizes that the factor f_1 for the solid is different from the one calculated for free atoms. A dashed horizontal line at 0 highlights the f_1 changes in sign. In the bottom frame the blue circles and the solid curve are the square non-linear susceptibility in units of the non-resonant part and the model for the renormalization factor respectively, plotted against the idler energy. The experimental data are taken from Tamasaku, Sawada, and Ishikawa [3].

difference method near-edge structure) [6] are able to faithfully reproduce the dispersion at the edges needed for the reliability of the model since they account for bonding and condensed-matter effects. Finally, a related cross-sectional enhancement effect has also been observed in resonant inelastic x-ray scattering RIXS experiments [5]. Therefore, very accurate RIXS and PDC experiments by XFELs can lead to more fundamental theoretical insight [7].

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Fano resonances of multipole surface plasmons in metallic nanohole arrays

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At the interface between a metal and a dielectric, a kind of surface bound state, called surface plasmon polariton (SPP), is created by the coupling between the plasma oscillation in the metal and the electromagnetic wave in the dielectric. Electromagnetic waves are confined near the interface by the SPP excitation, and causes strong enhancement of electric field, which depends strongly on the environment near the metallic surface. Utilizing this peculiarity of SPP, many researches have been conducted aiming to realize high-sensitivity biosensors and nanoscale optical devices, controlling the SPP characteristics by metallic nanostructures.

A metallic nanohole array is one of the simplest nanostructures; a metallic film perforated by a periodic array of subwavelength holes. As was found by Ebbessen et al. [1], the light transmission through this system can be resonantly enhanced by orders of magnitude larger than the expectation of the usual theory. There are some interpretations of this extraordinary optical transmission (EOT) [2], but the Fano resonance seems to give a unified view of the origin of EOT [3-5]. A metallic nanohole array fulfills the condition of the Fano resonance; direct transmissions through the holes and leaky bound states, i.e., SPPs coupled with the external radiation by the periodic array of holes as a diffraction grating.

Another peculiarity of this system is that external light can penetrate into the metal region using evanescent waveguide modes of the holes, and produce a kind of surface bound state that has similar property with SPP, even when the metal behaves as a perfect electric conductor (PEC) where SPP does not exist [6]. Therefore, the surface bound states in nanohole arrays of real metals are considered to be hybrid modes between SPPs of metal surface and the evanescent waveguide modes of holes, whose detailed characterization is necessary to understand fully the Fano resonance phenomena in this system.

In recent paper [7], we have shown that when the size of the nanohole occupies a large portion of the unit cell, the SPPs at both sides of the film are combined by the higher order waveguide modes of the holes to produce multipole surface plasmons: coupled surface plasmon modes with multipole texture on the electric field distributions. Due to the multipole nature of these modes, multiple dark modes coexist to produce a variety of Fano resonance structures on the transmission and reflection spectra as shown in Figure 1.

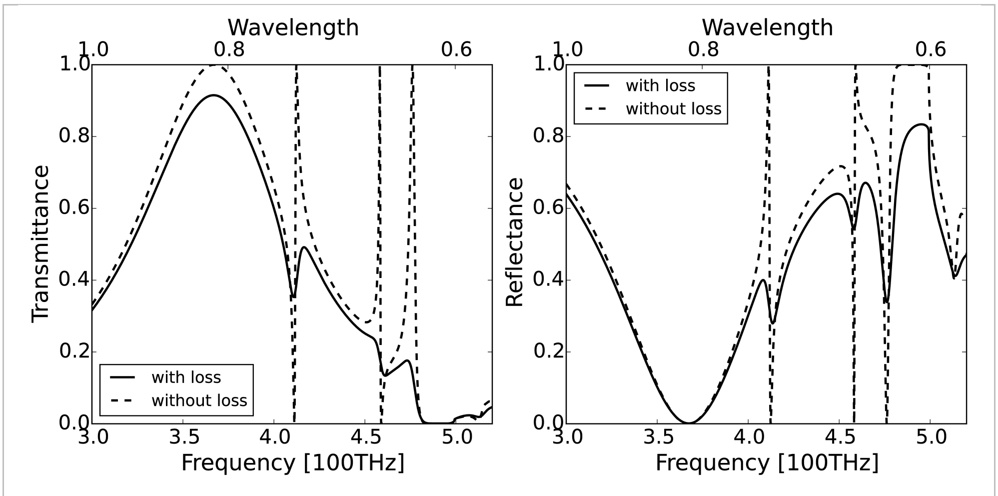

Figure 1: Fano structures in the transmission (left panel) and reflection (right panel) spectra.

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Fano resonance between Nambu-Goldstone modes and Higgs bound states in a superfluid

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We study collective modes of superfluid Bose gases in optical lattices combined with potential barriers [1]. In the vicinity of the quantum phase transition to a Mott insulator at a commensurate filling, particle-hole symmetry emerges such that there exist two types of collective mode, namely, a gapless Nambu-Goldstone (NG) phase mode and a gapful Higgs amplitude mode. We consider two kinds of potential barrier: one does not break the particle-hole symmetry while the other does. Including effects of both kinds of barrier, we derive the Ginzburg-Landau equation for the superfluid order parameter, which is used for analyzing the collective modes. In the presence of the former barrier, we find bound states of Higgs mode that have binding energies lower than the gap of the Higgs mode in bulk and are localized around the barrier. We also analyze tunneling properties of the NG mode incident to both barriers. It is shown that the latter barrier couples the Higgs bound states with the NG mode, leading to Fano resonance mediated by the bound states. This result exemplifies the ubiquity of the phenomenon of Fano resonance.

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Broad and Narrow Fano-Feshbach Resonances: Condensate Fraction of Cooper Pairs in the BCS-BEC Crossover

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Keywords: Fano-Feshbach resonances – ultracold atoms – BCS-BEC crossover

We extend our previous investigations of the fermionic condensation with a broad Fano-Feshbach resonance [1] by using the two-channel model developed for the 3D BCS-BEC crossover with a narrow Fano-Feshbach resonance [2]. We also discuss very recent results of quantum and thermal fluctuations in the 2D BCS-BEC crossover with a broad Fano-Feshbach resonance [3,4].
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PERALI

H3S

Metallic Superfluids and Superconducting Superfluids in "metallic hydrogen"-type systems

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Superconductors and superfluids; are systems that feature dissipationless electrical currents or mass flow. I will discuss, that "liquid metallic hydrogen-type" systems (i.e. metallic states of hydrogen or deuterium or their alloys with potential Cooper pairing instabilities for protons or condensation of deuterons) can allow states that cannot be categorized exclusively as a superconductor or superfluid. In the presence of a magnetic field, such systems can exhibit several phase transitions to ordered states, ranging from superconductors to superfluids [1]. Also they can form states that combine superconductivity and superfluidity, while violating their common properties such as Onsager's superfluid velocity quantization [2], London's electrodynamics and type-1/type-2 dichotomy of magnetic response 3].

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Crystal Structure of 200 K-Superconducting Phase in Sulfur Hydride System System

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Keywords: Sulfur Hydride, Sulfur Deuteride, Pressure-induced Superconductivity and Phase Transition, Synchrotron X-ray Diffraction Measurements

Superconductivity with the critical temperature T_c above 200 K has been recently discovered by compression of H_2S (or D_2S) under extreme pressure [1]. It was proposed that these materials decompose under pressure to elemental sulfur and hydride with higher content of hydrogen which is responsible for the high temperature superconductivity. In this study, we have investigated that the crystal structure of the superconducting compressed H_2S and D_2S by synchrotron x-ray diffraction measurements combined with electrical resistance measurements at room and low temperatures. We found that the superconducting phase is in good agreement with theoretically predicted body-centered cubic structure, and coexists with elemental sulfur [2], which claims that the formation of $3H_2S \rightarrow 2H_3S + S$ is occurred under high pressure [3].

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Hydrogen sulphide at high pressure: a strongly-anharmonic phonon-mediated superconductor

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Keywords : mechanisms for high Tc - anharmonicity

We use first principles calculations to study structural, vibrational and superconducting properties of H_2S at pressures $P \geq 200$ GPa. The inclusion of zero point energy leads to two different possible dissociations of H_2S, namely $3H_2S \rightarrow 2H_3S + S$ and $5H_2S \rightarrow 3H_3S + HS_2$, where both H_3S and HS_2 are metallic. For H_3S, we perform non-perturbative calculations of anharmonic effects within the self-consistent harmonic approximation and show that the harmonic approximation strongly overestimates the electron-phonon interaction ($\lambda \approx 2.64$ at 200 GPa) and T_c. Anharmonicity hardens H–S bond-stretching modes and softens H–S bond-bending modes. As a result, the electron- phonon coupling is suppressed by 30% ($\lambda \approx 1.84$ at 200 GPa). Moreover, while at the harmonic level T_c decreases with increasing pressure, the inclusion of anharmonicity leads to a T_c that is almost independent of pressure. High pressure hydrogen sulfide is thus a strongly anharmonic superconductor [1]. Finally, I will discuss new results in lower pressure the range, 130-200 Gpa, where the maximum of T_c has been observed [2].

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BIANCONI

SUPERCONDUCTIVITY

Elusive charge-density-wave order is now manifest: a bridge between underdoped and overdoped Cuprate Superconductors.

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Charge order, elusive and contrasted until 2012, is now ubiquitously observed in cuprates and most investigated among competing orders.
At high doping charge order follows as instability of correlated Fermi liquid with a "hidden" Charge Density Wave Quantum Critical point in the proximity of optimal doping as theoretically predicted since 1995 and now observed. CDW mostly dynamical, becomes long range when the 3D coupling becomes effective.
At very low doping, the doped charges aggregate in ferronematically ordered segments with broken rotational and inversion symmetries. This state with incommensurate spin order and low or no positional order, may evolve, by increasing doping, into charge ordered states of stripe type with tightly linked (as in LSCO) or independent (as in YBCO) spin and charge incommensurations. Both pictures are allowed in our scenario.

Studies of the Superconducting Order Parameter in Fe-based HTS

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Keywords: high temperature superconductivity – order parameter

Since the discovery of Fe-HTS in 2008 and until today, the pairing symmetry remains the focus of research [1]. The $s_{\pm}$ type symmetry appears in the spin-fluctuation-pairing theory [2]. Pairing mediated by orbital fluctuations [3] or shape resonances [4-6] leads to the s_{++} state. The experimental data on the order parameter in Fe-HTS are rather contradictive [7,8]. Here we report the results obtained with Fe-HTS compounds by several complementary techniques: line shape and T-dependence of the Andreev reflection (AR) spectra, specific heat $C_{el}(T)$, penetration depth $\lambda_{ab}(T)$-dependencies, and nonmagnetic disorder effect. Our results with FeSe, 122 and 1111 compounds may be summarized as follows: (a) the order parameter doesn't show zeroths though exhibits a strong anisotropy, (b) the intraband coupling is strong and much exceeds the interband one. Our results are in agreement with the extended s_{++} symmetry.

(i) For FeSe:S single crystals, both $\lambda_{ab}(T)$ and $C_{el}(T)$ can be well described by using a two-band model with two s-wave-like nodeless gaps [9].

(ii) For Na(Ca)Fe_2As_2 and Ba(K)Fe_2As_2) we found that $\lambda_{ab}(T)$ and $C_{el}(T)$ data also show contributions from two gaps (Fig1a). The AR spectroscopy directly reveals two nodeless gaps: a large Δ_L = 6–8 meV with ~30% anisotropy in the k space, and a small $\Delta_S = 1.7 \pm 0.3$ meV. A puzzling issue is the potential presence of a third gap in the 122 systems [10].

Studies of the disorder impact on T_c are motivated by its sensitivity to the order parameter symmetry [11,12]. In case of the $s_{\pm}$ symmetry the nonmagnetic defects should quickly suppress T_c due to the interband scattering. In contrast, for the s_{++} symmetry, the nonmagnetic defects should have no effect on T_c until conduction decreases to a critical value and T_c vanishes. The 50-nm-thick $Ba(Fe_{0.94}Co_{0.06}As)_2$ films were irradiated with 200 keV He^+ ions generating nonmagnetic point defects of atomic displacement. The experiment [13] shows that T_c slowly decays with irradiation and reaches zero at a critical disorder $k_F l$ =1, the result that is inconsistent with the $s_{\pm}$ symmetry.

(iii) 1111 system. The superconducting gaps and the $\Delta(T)$ dependencies were probed by AR spectroscopy over the wide range of temperatures (Fig.1b) [7,9,14]. For Sm-, Gd-, and La-

1111 the $\Delta_{L;S}(T)$ dependencies are well-fitted with a two-band system of gap equations. The intraband coupling ratio $\lambda_{SS}/\lambda_{LL}$ = 0.6-0.8 is much larger than the average interband one, $(\lambda_{LS}\lambda_{SL})^{1/2}/\lambda_{LL}$ =0.05 – 0.1.

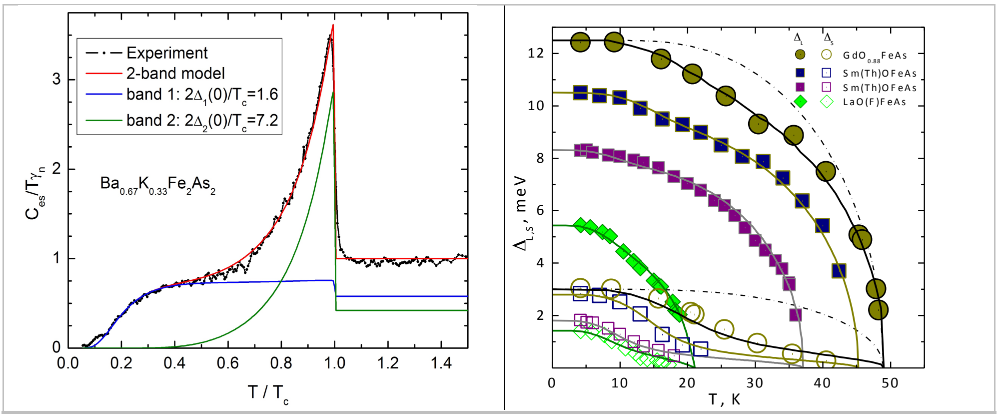

Figure 1: (a) Typical $C_p(T)$ dependence for BKFA, and the contributions of two bands. (b) $\Delta_{L,S}(T)$ dependencies for La-, Gd- and Sm-1111. Dash-dotted line shows the BCS curve

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Fluctuations of "Hidden Order" as Cooper Pairing Glue

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Keywords : high Tc cuprates –'hidden order' – pairing glue

Fluctuations of the "hidden order" as an origin of the Cooper pairing glue in high-Tc superconductors are considered. New scenario is based on the recent publications [1]-[3] that introduced Euclidean crystallization in correlated Fermi-system as an origin of a "hidden order", that breaks translational invariance of the system along the Matsubara time axis. Spin-density wave with Matsubara time-periodic amplitude, leading to zero scattering cross section, is considered as a particular case of the "hidden order". Fluctuations of this peculiar order parameter are found self-consistently and their role in providing a Cooper pairing "glue" for the Fermi-system is investigated. The work advances the previous results [1-3].
In [1] it was proven analytically that self-consistent Matsubara time-periodic order parameter has zero scattering cross section and, therefore, is a candidate for a "hidden order", emerging in the high-Tc cuprates. In this work spectrum of the "hidden order" fluctuations is found. Before its renormalization by the fermions the spectrum possesses some modes with the negative eigen energies [2], [3], signifying well known instability of the bare "instantonic-lattice" solution along the Matsubara axis. Nevertheless, the self-consistent solution for the fermionic system with coexisting Cooper-pairing and instantonic antiferromagnetic magnetization does not show the "negative modes", as is calculated in the present work and discussed in relation with the Cooper-pairing 'glue' mechanism in high-Tc cuprates.

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Coherent and Collective Properties in UO(2+x): A Polaronic Bose-Einstein Condensate]

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Keywords : Bose-Einstein condensate – polarons – UO_{2+x}

Bose-Einstein condensates have been made from atoms, polaritons, magnons, and excitons, posing the question of whether they can also be composed of polarons so as to combine coherently charge, spin, and a crystal lattice. We have performed a large number of ultrafast pump-probe experiments on photoexcited UO_2, local and electronic structure studies of O-doped UO_{2+x}, and EPR measurements on the spins, all of which give highly unusual or unique results [1, 2]. These demonstrate collective behavior in terms of aggregation and self-organization of the polarons into a separate phase within the host. They also show both indirect and direct evidence for extreme coherence and possibly superfluidity of some of the atoms within this phase. Our interpretation is that the photoinduced and chemically doped polaronic phases are very similar and constitute a polaronic BEC. That some of these signatures of coherence in an atom-based system extend to 50 K and even ambient temperature indicates that it is not a ground state property. The characteristics of the dynamical polarons obtained from the neutron and x-ray scattering and absorption measurements [3] suggest a novel mechanism that could be a synchronized, dynamical, charge transfer or disproportionation excitation involving the confluence of the non-degenerate valence-lattice dynamics of these polarons with the structural chemistry of uranium oxides. The condensation could be promoted via the solid state analog of a Feshbach resonance in which the two U species involved in the charge transfer represent the open and closed channels. Since a Feshbach-shape type resonance has been shown to be coherent if it connects two coherent states [4], by equivalence a synchronous or coherent resonance would also make these states coherent. We now also have evidence from a combination of RIXS, O XAS, and time-resolved photoemission that doping causes a substantial closing of the Mott gap. These intragap states that are possibly an intrinsic property of 5*f* Mott insulators raise the possibility of a two band structure at or near the Fermi level that is also coupled to coherence [5, 6]. In addition to the increasing likelihood that $UO_{2(+x)}$ hosts a macroscopic quantum object that can be created in easily weighed quantities by chemical doping, persists to ambient temperature, and resides in a bulk solid, this type of mechanism could be of interest because it relates the BEC in $UO_{2(+x)}$ to the BCS condensate in cuprates via the dynamical polaron that is common to both [3, 7].

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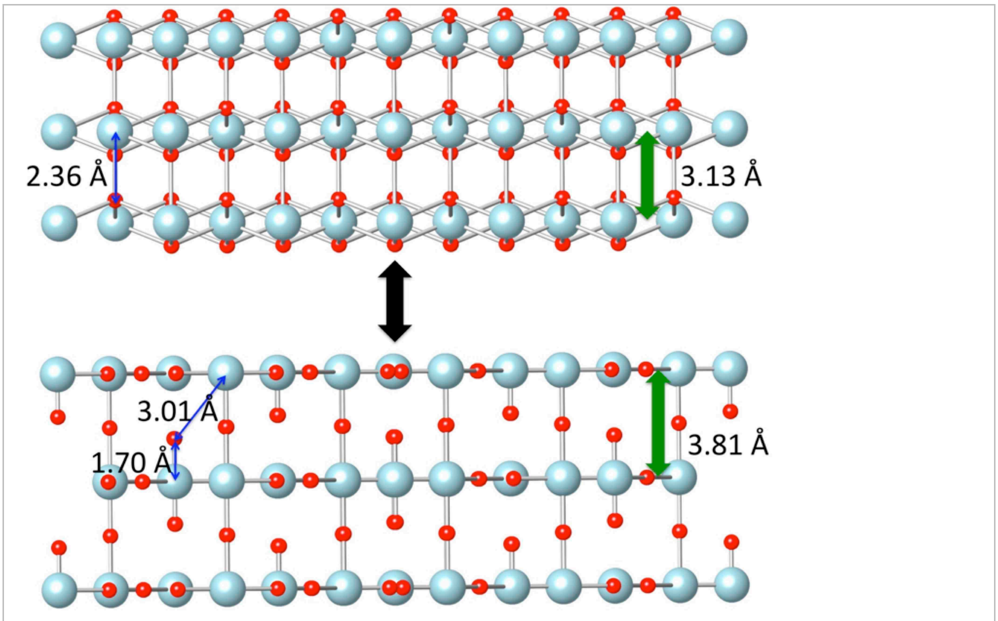

Figure 1: The collective polaron in $UO_{2(+x)}$. For a [111] phonon, the U(IV, V) structure (top) is stable on the contracted side of the vibrational excursion. On the expanded side the interplanar bonds are disrupted by the increased separation, stabilizing the planar U(IV, VI) configuration with terminal oxo moieties via the disproportionation excitation 2U(V)↔U(IV)+U(VI) and converting the kinetic energy of the vibration into the enthalpy of the bonds. The coherent polaron hopping of this Feshbach-shape resonance promotes coherence in the states it connects, giving the BEC.

Non-euclidean geometries in high temperature superconductors]

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Functional materials like high temperature superconductors (HTS) and complex oxides are characterized by an *intrinsic complexity*. Indeed, they show the coexistence of multiple striped-orders like Charge-Density-Wave (CDW), Spin-Density-Wave (SDW) and defects that get organized in different striped nano-domains and exhibit a strong dynamic competition [1]. The study of the interplay among these multiple orders is challenging because their critical dynamics are strongly connected to the emerging of functional properties at the macroscopic scale. The first step to understand the competition between these multiple striped orders is the investigation of their spatial-organization. On this purpose we developed a set of innovative techniques like scanning micro X-ray diffraction (µXRD) and resonant scanning micro X-ray diffraction (RµXRD) to directly visualize the spatial-organization of the SDW, CDW and defects orders. We evidenced a common nanoscale phase separation scenario, characterized by the coexistence of competing scale-free networks of self-organized nano-domains promoting superconductivity [2-9]. Recently we discovered that the CDW stripes get self-organized in nano-domains defining a complex non-euclidean space available for the superconducting phase (Fig. 1) [10]. This open the way for completely new percolation theories for the interpretation of the microscopic mechanism of high temperature superconductivity.

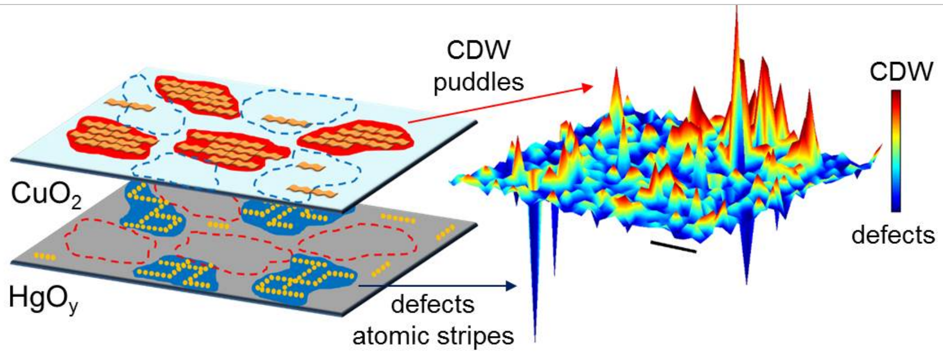

Figure 1. Spatial anti-correlation between CDW and defects domains [10].

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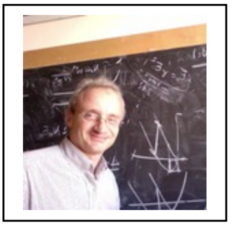
COMPLEXITY

Nanoscopic inhomogeneity, intrinsic charge instability, and novel metal-to-superconductor quantum criticality in oxide heterostructures



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Keywords: superconducting oxide interfaces, electronic phase separation, density-driven quantum criticality

Experiments in oxide interfaces like $LaAlO_3/SrTiO_3$ or $LaTiO_3/SrTiO_3$ (LXO/STO) heterostructures, clearly indicate that the 2D electron gas and the resulting superconducting state at the interface is strongly inhomogeneous on the nanoscopic scale[1] (see Fig. 1).

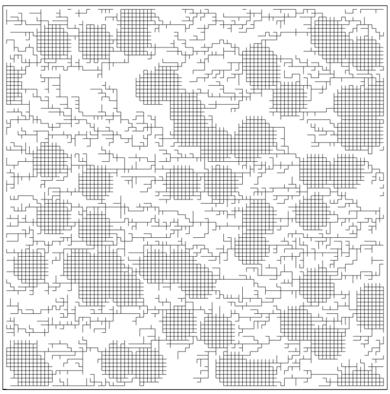

Fig.1 from Suppl. Mat. Ref. 1

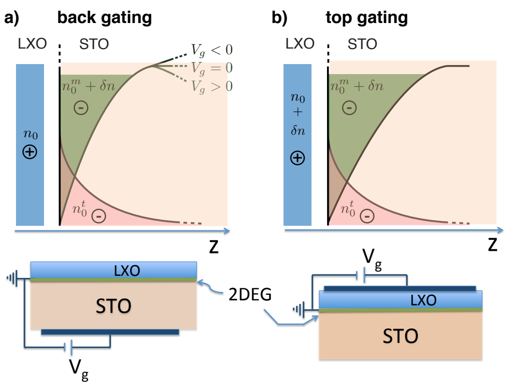

Fig. 2 from Ref. 3

Microscopic mechanisms for electronic phase separation (EPS) based on Rashba spin-orbit coupling (RSOC) [2] and/or electrostatic electron confinement at the interface [3] (see Fig. 2) are investigated to establish a possible intrinsic origin for this inhomogeneous character of LAO/STO or LTO/STO superconductors.

Both RSOC and electrostatic confinement not only provide an intrinsic mechanism for the observed inhomogeneity, but also open the way to new interpretations of the observed quantum critical behaviour of superconductivity in LXO/STO [4-6]. We investigate the effects of temperature, gating, and magnetic field on the charge instability finding a novel type of SC-to-metal quantum criticality related to the vanishing of the critical temperature of the EPS [5,6].

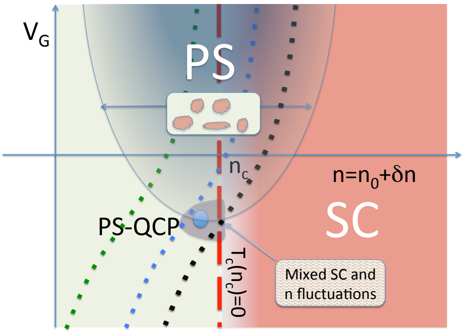

Fig. 3 from Ref. 5 Schematic phase diagram of the LXO/STO interface. Differently prepared samples follow the different dotted lines upon changing the backgating potential

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Zero Helicity States in the $LaAlO_3$-$SrTiO_3$ interface

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Keywords : interface superconductivity and magnetism – order parameter theory – torque magnetometry

Interfaces are promising candidates for the construction of electronic devices [1]. It is remarkable that in the interface between two insulators, $LaAlO_3$ and $SrTiO_3$, a two-dimensional electronic liquid is formed and displays the coexistence of magnetism and superconductivity. High-resolution magnetic torque magnetometry and transport measurements give direct evidence of magnetic ordering of this two-dimensional electron liquid at the interface from well below the superconducting transition to up to 200 K. Interestingly there is an in-plane magnetic moment that persists even to the lowest applied field of 5 mT nearly perpendicular to the interface causing a torque [2]. It is well-known that the torque measurements only probe macroscopic aspects of a condensate, thus their description is attainable through an order parameter theory, which is pursued in this work. For instance, a microscopic theory of the high-T_c superconductors is still missing and yet the torque measurements have been successfully explained in the past 25 years by the London theory, which is a macroscopic theory and gives several interesting parameters, such as the mass anisotropy of the condensate [3]. Here we find that this natural magnetic moment of the $LaAlO_3$-$SrTiO_3$ interface is caused by the presence of skyrmions and of an asymmetry between the two sides of the interface. Our fitting parameters to the experimental data are the thickness and the mass anisotropy, found to be (1.8 nm, 8) for $LaAlO_3$ and (2.5 nm, 8.5) for $SrTiO_3$. The charged carriers are confined to such thickness in our theory and from the zero helicity condition it follows an exponential decay of the order parameter away from the two-dimensional interface, which is magnetic field dependent. Thus the two found regimes for

the magnetic moment with respect to the applied field are an increasing and a decreasing one, as the ratios between the magnetic length and the thickness are varied. This successful fitting of data by theory solely relies on the kinetic energy of a condensate where the inversion symmetry is broken by the onset of zero helicity states. Topological excitations result from this new mechanism and they are admixtures of vortices and skyrmions. The skyrmions solutions are associated to the trapped magnetic field streamlines around the interface [4,5]. Interestingly the present theory has two-order parameters with distinct properties across the two-dimensional interface, namely symmetrical and anti-symmetrical, respectively. Therefore the existence of continuum states outside and of two discrete ones inside the interface is suggestive of an intrinsic Fano resonance in the configuration interaction between open and closed scattering channels [6].
The present mechanism for the breaking of the reflection symmetry of the kinetic energy reveals first order equations to obtain the order parameter and the local magnetic field. These equations belong to the family of topological equations to which belong the Abrikosov-Bogomolny [7,8] and the Seiberg-Witten equations [9], the latter describe four dimensional massless magnetic monopoles. The topological equations were first used in A. Abrikosov's original work to discover the vortex lattice and later rediscovered by E. Bogomolny [8] in the context of string theory and shown to solve exactly the Ginzburg-Landau second order equations for a particular value of the coupling constant ($\kappa=1/\sqrt{2}$). The Abrikosov-Bogomolny and Seiberg-Witten equations are also associated to spinor algebras, like the present ones which are associated to the Pauli matrices.

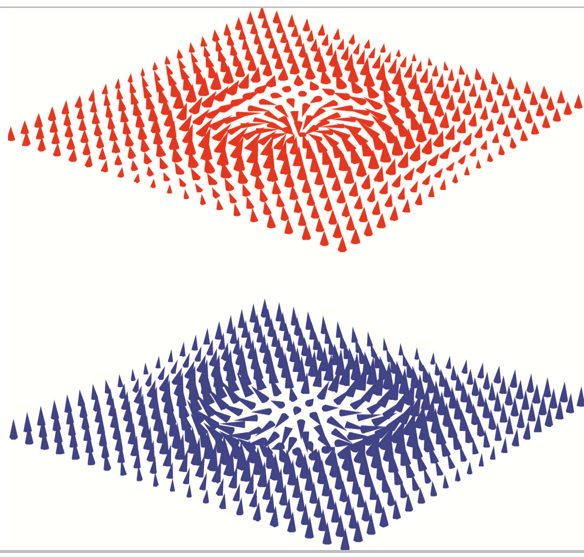

Figure 1: The magnetic field of a skyrmion, as seen from above (top, red) and below (bottom, blue) the interface. The arrows indicate the direction of the magnetic field. Notice the existence of a sinkhole (top) of magnetic field that becomes a fountain (bottom). Closed magnetic field streamlines double cross the interface.

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Quantum simulation with integrated photonics

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We experimentally demonstrate that particle statistics strongly affects quantum mechanical decay in a multiparticle system. By considering propagation of two-photon states in engineered photonic lattices, we simulate quantum decay of two noninteracting particles in a multilevel Fano-Anderson model. Remarkably, when the system sustains a bound state in the continuum, fractional decay is observed for bosonic particles, but not for fermionic ones. Complete decay in the fermionic case arises because of the Pauli exclusion principle, which forbids the bound state to be occupied by the two fermions. Our experiment indicates that particle statistics can tune many-body quantum decay from fractional to complete

Autoionization processes in helium clusters

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Keywords: Autoionization – Helium clusters – Interatomic Coulombic decay

Electronic correlation is of fundamental importance in atomic and molecular systems. Especially the interaction of energetic photons with multiple electron systems is governed by electron correlation leading to processes such as shake-off in single photon double ionization [1], post collision interaction in Auger processes [2], and autoionization of doubly-excited states [3]. In general, the helium (He) atom has served as a model system for studying electronic correlation effects in detail due to its simple electronic structure [4].

To explore the nature of highly excited correlated states in condensed phase systems, one can introduce weak interactions between atoms by forming van der Waals clusters of variable size. In recent years, small van der Waals clusters have been a fertile ground for investigating correlation effects such as interatomic Coulombic decay (ICD) [5]. In that process, the internal energy stored in the excitation of one atom or ion is transferred to its neighbor which in turn is ionized. Surprisingly, ICD was found to occur even in He_2 dimers which have an internuclear separation of 58 Å [6].

While autoionization processes have been studied in some detail for the heavy rare gases condensed into clusters [7] or bulk [8], He clusters are much less well studied at high photon energies where He is photoexcited or ionized. However, He clusters are particularly attractive model systems due to the mentioned fundamental importance of the He atom on the one hand. On the other hand, He droplets have a homogeneous density distribution due to their quantum liquid nature in contrast to the other rare gas clusters which feature a variety of geometric configurations as function of size. Furthermore, the extremely high ionization energy and the chemical inertness make He the ideal host matrix for embedding other species ("dopants") to study heterogeneous nanosystems with strongly differing properties of the constituents [9,10].
In this contribution we review various autoionization processes recently observed in pure and doped He droplets. From the emission of ultra-slow electrons as well as Rydberg atoms

upon excitation below the He ionization threshold [11,12], which is ascribed to a relaxation process akin to vibrational autoionization [13], over droplet-enhanced ICD and collective autoionization (CAI) of multiply excited He droplets [14], up to broadened and blue-shifted Fano resonances upon double excitation (see Fig. 1) [15], He droplets ensure many surprises.

Dopant atoms or clusters embedded in He droplets or attached to the He droplet surface are found to undergo efficient Penning or charge transfer ionization when exciting or ionizing the hosting He droplets, respectively [16]. Dopants whose first and second ionization energies fall below the first ionization energy of He (e.g. magnesium) can even be doubly ionized by a process termed electron-transfer mediated decay (ETMD) [17]. Besides the curiosity-driven research on these fundamental autoionization processes of complex systems, the detailed characterization of secondary ionization channels upon irradiation with energetic radiation is instrumental for future studies of photoelectron spectra of droplet-isolated species or for upcoming diffraction imaging experiments [18].

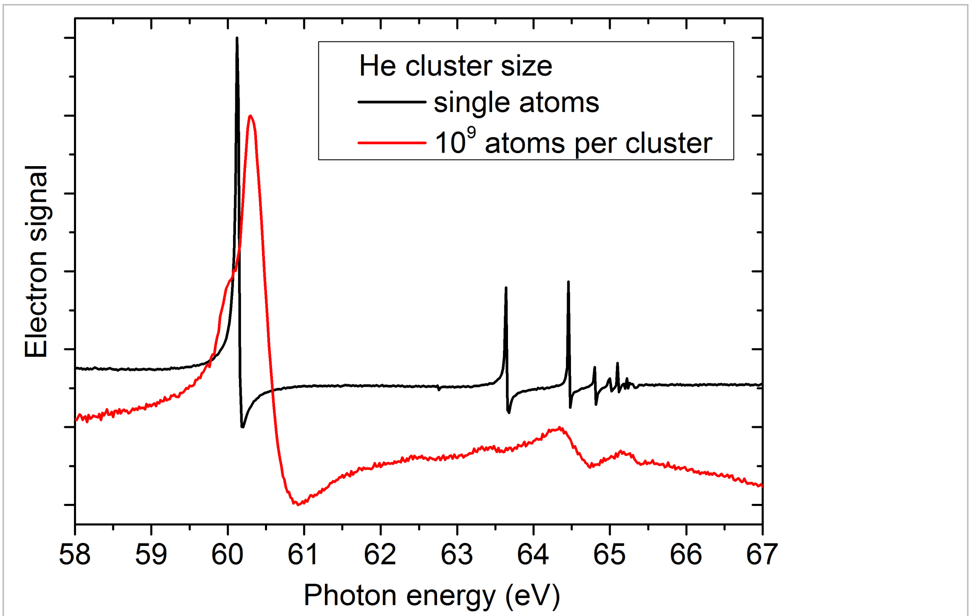

Figure 1: Photoelectron signals as a function of synchrotron photon energy recorded for an atomic He beam (black, He nozzle temperature T_{He}=40 K) and for large He clusters (red, T_{He}=9 K).

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Optical spectroscopy in inhomogeneous superconductors

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Keywords : inhomogeneity- collective modes

In the last few years an increasing experimental evidence has been accumulating that in materials like NbN, InOx and TiN a direct superconductor-to-insulator transition (SIT) occurs by increasing disorder. In addition, as the SIT is approached the superconducting state develops an emergent inhomogeneity of the electronic properties, that has been clearly identified in tunnelling experiments. Here I will review our theoretical progresses in the understanding of the nature of this glassy-like inhomogeneous superconductor[1,2], with particular attention to the identification of its signatures in the low-frequency optical spectroscopy[3,4].

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Quantum interference and unified Fano-Rice theory of phonon infrared properties in graphenes.

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The detection and analysis of the spectral properties of optical phonon in single-layer and multilayer graphene provides a powerful tool not only for a careful characterization of the systems but also for investigating the role of the underlying electron-phonon interaction.
Recent experiments in gated bilayer graphene revealed a clear phonon resonance at 1590 cm-1 with several interesting features, as for instance a giant enhancement of the phonon intensity as a function of the gate voltage as well as a pronounced Fano lineshape asymmetry. In this talk I will discuss how these features can be analyzed and predicted on a microscopic quantitative level using a charge-phonon theory applied to the specific case of graphene systems.
We show in particular how the phonon intensity and the Fano asymmetry are strictly related, stemming out from the quantum interference between the electronic and phononic degrees of freedom. Within this context we are also able to elucidate the relative role of the Eu and Eg phonon modes in regards to the infrared activity and the Fano asymmetry of the observed phonon peaks.
We present thus a complete phase diagram for the strength of the phonon modes and their Fano properties as functions of the chemical potential and of the gated-induced electronic gap, showing that a switching mechanism between the dominance of the Eu or Eg mode can be controlled by the external gate voltage.
Our work permits thus reconciling within a unique theoretical approach the phonon-peak features observed by different experimental groups, and it provides an analytical tool for predicting and controlling on a quantitative level the spectral properties of the phonon resonances in the infrared spectra of graphenes.

Electronic polymers and soft-matter-like physics in underdoped cuprates

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Keywords : nematic electronic phases – electronic polymers – underdoped cuprates

Empirical evidence in heavy-fermion materials, pnictides, and other systems suggests that unconventional superconductivity appears associated to some form of electronic order in real space. For the high-T_c superconducting cuprates, despite several proposals, the emergence of order in the phase diagram between the commensurate antiferromagnetic state, occurring at zero and very low doping, and the superconducting state, that establishes within a dome-shaped region of the phase diagram around optimal doping, is as yet not well understood. According to our proposal [1], in this regime doped holes assemble in *electronic polymers* sustaining a vortex and an antivortex of the antiferromagnetic background at the two end points. Within a Monte Carlo study, we find that in clean systems, when the temperature is lowered, the polymer melt condenses first in a smectic state and then in a Wigner crystal, both with the addition of inversion symmetry breaking, being therefore labeled as ferro-phases (ferrosmectic and ferrocrystal). Disorder blurs the positional order leaving a robust inversion symmetry breaking and a ferronematic order, accompanied by vector chiral spin order, and with the persistence of a thermodynamic transition towards the polymer melt with increasing the temperature (see Fig. 1). Such electronic phases, whose properties are reminiscent of soft-matter physics, produce charge and spin responses in good agreement with experiments [2,3].

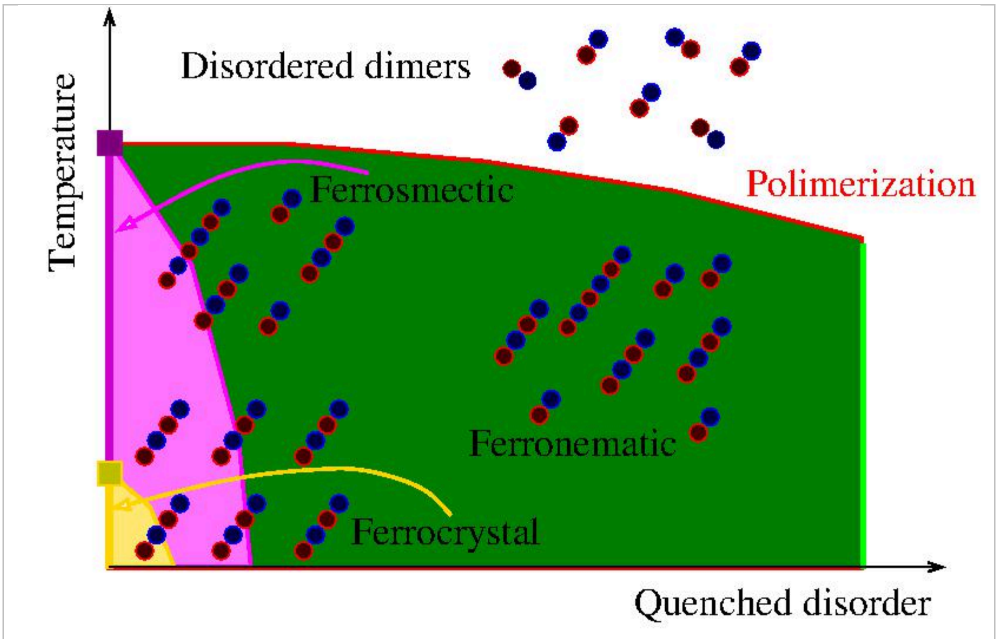

Figure 1: Sketchy phase diagram in the Temperatur vs. Quenched disorder plane, illustrating the various ordered phases resulting from the polimerization of dimers of vortices (red circles) and antivortices (blue circles) of the antiferromagnetic background, associated with doped holes in underdoped cuprates. The disordered dimers undergo a polimerization process at temperatures below the red line. The polymers order in phase reminiscent of soft-matter physics, and all the ordered phases break inversion symmetry, being therefore labeled as ferro- phases. A sharp transition to the ferrosmectic and ferrocrystal phases only exists in the absence of disorder (magenta and yellow boxes, respectively). In the presence of disorder, these phases survive as short-range-ordered phases, crossing over to a robust ferronematic phase, rapresented by the green area. The crossover regions for the ferrosmectic and ferrocrystal short-range-ordered phases are the light-magenta and light-yellow shaded areas, respectively.

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HISTORY & NEW PHYSICS

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A. MARCELLI

POSTERS

Nature and Raman signatures of the Higgs (amplitude) mode in the coexisting superconducting and charge-density-wave state

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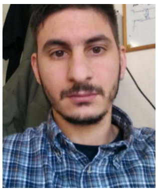
Keywords : Higgs mode in superconductors

We investigate the behavior of the Higgs (amplitude) mode when superconductivity emerges on pre-existing charge-density-wave-state. We show that the weak overdamped square-root singularity of the amplitude fluctuations in a standard BCS superconductor is converted in a sharp, undamped power-law divergence in the coexisting state, reminiscent of the Higgs behavior in Lorentz-invariant theories. This effect reflects in a strong superconducting resonance in the Raman spectra, both for an electronic and a phononic mechanism leading to the Raman visibility of the Higgs. In the latter case our results are relevant to the interpretation of the raman spectra measured experimentally in the $NbSe_2$.

NONLINEAR TERAHERTZ BEHAVIOURS OF THE BI_2SE_3 TOPOLOGICAL INSULATOR



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Keywords : Terahertz, Topological Insulator, Nonlinear

Nonlinear light-matter interactions play a key role in modern photonics and spectroscopy. The investigation of these phenomena have been allowed by materials or devices that manifest a strong nonlinear response in infrared and visible spectral range. Terahertz region (1 THz = 33 cm^{-1} = 300 μm = 4 meV) has seen recently a tumultuous technological and scientific progress, however the lack of systems which strongly interact with light in such a spectral range limit the extension of the non-linear processes at THz frequencies. Recently, theoretical models have predicted a strong nonlinear THz behavior in materials hosting Dirac electrons which has been estimated to be ten order of magnitude larger than massive electron plasma in conventional metals. In fact, in these systems the linear energy/momentum dispersion $E = v_F p$ drives a nonlinear intra-band current [1-2]. This happens when the momentum of external THz radiation starts to be comparable than the Fermi momentum ($Q=P_{THz}/P_F \sim 1$).
Topological insulators (TI) are quantum systems characterized by an insulating electronic gap in the bulk and Dirac surface states [3].
Here we report on the first observation of strong nonlinear THz absorption induced by intra-band current in Dirac surface state in Bi_2Se_3 topological insulator. The electromagnetic response in the THz regime has been studied over seven decades of electric field amplitude, from 0.1 V/cm ($Q<<1$) up to 1.5 MV/cm ($Q>>1$) by the SPARC linear accelerator-based THz source, which can deliver highly intense broadband THz pulses with femtosecond shaping [4]. The figure 1 shows the integrated transmittance of a Topological Insulator Bi_2Se_3 sample integrated over a frequency range from 500 GHz to 2 THz and plotted *vs.* the THz electric field. At low-field the transmittance is nearly flat corresponding to the linear response regime. For increasing electric fields the TI sample starts to be more transparent due to nonlinear current [5].

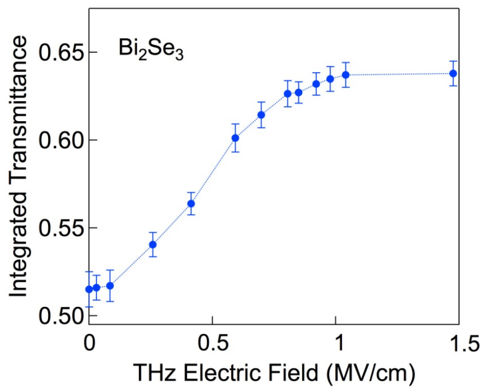

Figure 1: Integrated transmittance as a function of THz electric field amplitude.

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Band structure and electron-phonon coupling in H_3S: a tight-binding model]

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Keywords : High Tc superconductivity – Electronic properties

We present a robust tight-binding description, based on the Slater-Koster formalism, of the band structure of H_3S in the Im-3m structure, stable in the range of pressure P = 180-220 GPa. [1] We show that the interatomic hopping between the 3p sulphur orbitals is fundamental to capture the relevant physics associated with the Van Hove singularities close to the Fermi level. Comparing the model so defined with density functional theory calculations we obtain a very good agreement not only of the overall band-structure, but also of the low-energy states and of the Fermi surface properties (see Figure 1). The description in terms of Slater-Koster parameters permits us also to evaluate at a microscopic level a hopping-resolved linear electron-lattice coupling which can be employed for further tight-binding analyses also at a local scale.

References in square bracket [1] in the text.

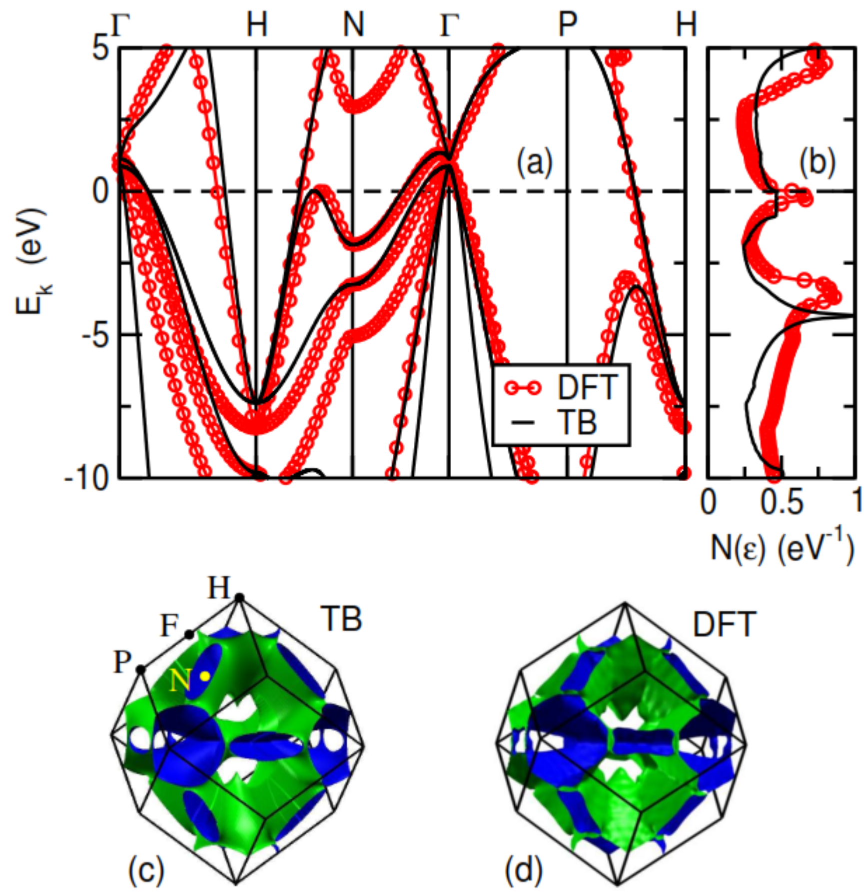

Figure 1: Panel (a): first-principle band structure of H_3S (red dots), compared with the band structure resulting from the tight-binding model (black solid lines). Panel (b): corresponding density of states (DOS). The black dashed lines mark the position of the Fermi level E_F. The comparison of the Fermi surfaces of the most relevant band obtained from first-principle calculations and from our tight-binding model is shown in panels (c)-(d).

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NEW TEXTURES & MATERIALS

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