Mechanisms for Metastable Photo-Induced Superconductivity, far above Tc

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Advances in the control of intense infrared light have led to the striking discovery of metastable superconductivity in K3C60 at 100K, lasting more than 10 nanoseconds, four orders of magnitude above characteristic microscopic time-scales. Inspired by these experiments, we discuss possible mechanisms for long-lived, photo-induced superconductivity far above Tc. Motivated by the nature of electron-phonon coupling in K3C60, we first focus on a microscopic model of an optically driven local vibrational mode coupled to the inter-band electronic transition of narrowly dispersive bands. Within our model, we develop a microscopic mechanism for photo-controlling the pairing interaction by displacively shifting this mode. Leveraging these microscopics, we explore two, phenomenologically distinct, pictures for long-lived, light-induced superconductivity far above Tc. We first investigate photo-induced superconductivity arising from the metastable trapping of a displaced phonon coordinate in a free energy landscape. We then propose a dynamical route to long-lived superconductivity: Quasi-particle trapping. Within this paradigm, the slow equilibration of quasi-particles enables a long-lived, non-thermal superconducting gap. We conclude by discussing implications of both scenarios to experiments that can be used to discriminate between them. Our work provides possible mechanistic explanations for photo-induced superconductivity in K3C60 while also offering a theoretical basis for exploring long-lived, non-equilibrium superconductivity in other quantum materials.

Dynamics of the electric field-induced Mott transition in $GaMo_4S_8$ single crystals and epitaxial 1T-$TaSe_2$ monolayers

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Mott materials are archetypal strong electronic correlations systems. The study of their non-equilibrium properties is not only a promising approach for the understanding of these systems but is also essential for optimizing Mottronic devices currently under development.

This presentation will start with a brief review our current knowledge on the electric field induced, out of equilibrium Mott transition in canonical Mott semiconductors [1]. We will then first discuss the evolution of the volatile transition as a function of the sample and electrodes geometry, using an advanced multiple probes tunneling microscopy setup [2]. Our results agree with a linear decrease of the characteristic delay time of the transition with the system size, underlining the high potential of Mott materials for the development of fast, low consumption neuromorphic devices. Secondly, we will present our recent results on a novel two-dimensional Mott insulator, 1T-TaSe2 epitaxially grown on a GaP substrate [3].

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[2] H. Koussir, I. Lefebvre, M. Berthe, Y. Chernukha, J. Tranchant, B. Corraze, E. Janod, L. Cario, B. Grandidier, and P. Diener, J. Phys.: Conf. Ser. **2164**, 012046 (2022).

[3] H. Koussir, Y. Chernukha, C. Sthioul, E. Haber, N. Peric, L. Biadala, P. Capiod, M. Berthe, I. Lefebvre, X. Wallart, B. Grandidier, P. Diener, Nano Lett. 2023.

Ultrafast modification of lattice coherences in photoinduced insulator-to-metal phase transition in a rare-earth nickelate

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The importance of electronic and lattice degrees of freedom in the insulator-to-metal transition in rare-earth nickelates is a long-standing question. In our work, we apply broadband ultrafast transient reflectivity spectroscopy to study photoinduced insulator-to-metal transition in $NdNiO_3$. The measurements are performed at 77 K (semiconducting phase). We find that upon crossing the

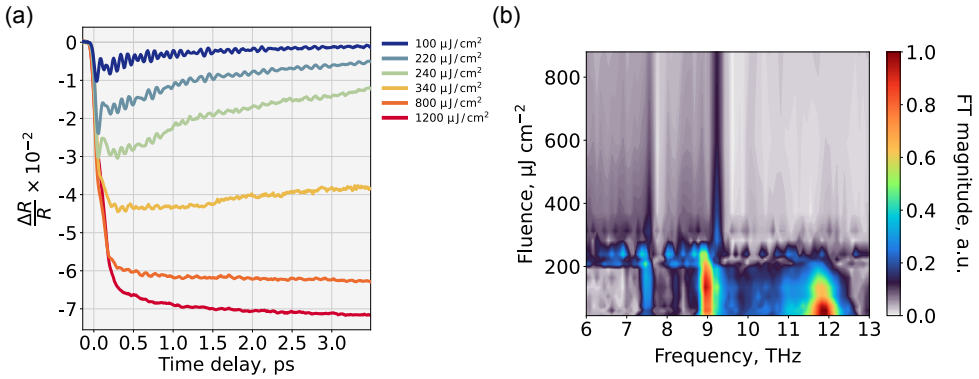

Figure 1. (a) Differential reflectivity transient traces at 1.82 eV probe photon energy for select pump fluences. (b) Fourier transform of the oscillating component of 1.82 eV transient traces for different pump fluences. The Fourier spectra are normalized to the pump fluence.

threshold fluence around $\Phi^* = 230$ μJ cm^{-2} both incoherent and coherent components of the signal experience drastic changes. As shown if Figure 1a, at increasing pump fluence the differential reflectivity signal changes its dynamics: whereas at low fluences the fast drop of the reflectivity is recovered on picosecond timescale, for the excitation densities exceeding Φ^*, a formation of a metastable state with a long recovery time is observed. Figure 1b demonstrates that for fluences below and above the Φ^* the coherent phonon spectra are the ones found in the low-temperature monoclinic and high-temperature orthorhombic phases, respectively, indicating an ultrafast modification of the lattice coherences. We demonstrate that above the transition threshold fluence, the changes of the coherent phonon spectra appear within ca. 100 fs upon photoexcitaiton, which is similar to the timescale of electronic modifications.

Title: **2D Terahertz spectroscopy of collective excitations.**

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Affiliation: *ETH Zurich*

Abstract: Two-dimensional terahertz spectroscopy (2DTS), a terahertz analogue of nuclear magnetic resonance, stands as a novel technique poised to address numerous open questions in complex condensed matter systems. The conventional theoretical framework, widely used for interpreting multidimensional spectra of discrete quantum-level systems, falls short in capturing the continua of collective excitations in strongly correlated materials. In this talk, we provide a pedagogical introduction to the technique in a language suitable for condensed matter systems, emphasizing its unique capabilities for interrogating the properties of these systems. We focus specifically on a prototypical example, the Josephson plasmon in layered cuprates, and discuss how this multidimensional spectroscopy technique can shed light on the underlying physics, in particular regarding temperature effects, disorder, and its phase transition.

The ELBE High-Power THz Sources – Tunable Coherent THz for Driving Nonequilibrium and Nonlinear Dynamics

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The FELBE FELs at the ELBE Center for High-Power Radiation provides ultrashort THz pulses that are well suited for driving many types of nonequilibrium and nonlinear dynamics. The broad and continuous tunability (1.2 – 60 THz) and narrow bandwidth ($\leq$ 2.5 %) of the FELBE FELs enable selective coupling of to specific electronic or structural modes in matter. Experiments at FELBE have explored the interaction of intense THz fields not only in solid, but also in liquid phase matter. Highlights from these studies, particularly in highly correlated materials will be presented along with the potential for further exploration of THz-driven phase transitions with the next generation of advanced high-field THz sources at the heart of the proposed successor to ELBE. The proposed new facility, **DALI**, would achieve an increase in pulse energy of up to three orders of magnitude, while also providing greater flexibility of experimental parameters along with new methods for probing THz-driven structural dynamics by ultrafast electron diffraction (UED) and time-resolved angle-resolved photoelectron spectroscopy (tr-ARPES).

Photocontrol of multiferroic $BiFeO_3$ via structural modification coupled with photocarrier

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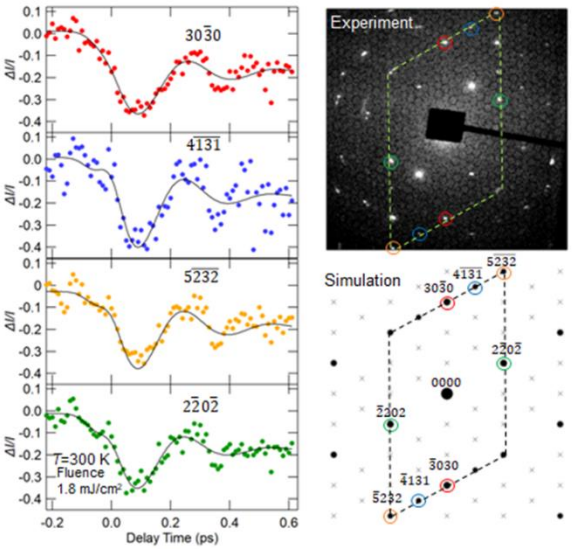
Ultrafast control of ferroelectricity and magnetism by light is essential for future development in multiple functioning devices. Here, we report the lattice and electronic state dynamics accompanied by the photo-modulation of electric dipole in a multiferroic $BiFeO_3$ thin film using optical pump-probe measurements and ultrafast electron diffraction (UED) with <100 fs time resolution. The photoinduced suppression of second harmonic generation yield and emergence of the in-gap absorption within 200 fs indicates the disappearance of the electric dipoles by introducing the photoexcited carriers. In addition, the subsequent structural dynamics involve a strong oscillation with a frequency of ~3.3 THz, as shown in the figure. Based on a theoretical calculation, this oscillation can be attributed to an unexpectedly softened phonon due to coupling with a photocarrier, similar to the phonon-dressed-exciton state. The comprehensive study shows that photoexcitation coupled with the lattice vibration mode can simultaneously realize the ultrafast switching of electric and magnetic orders at room temperature.



Result of the time-resolved UED

Signatures of Jahn-Teller-like magnetic instability in $TbFeO_3$ and dynamical strong coupling of Fe spins and Tb orbitals

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The problem of resonant coupling between photons and two-level atoms has been one of the most fruitful and fundamental questions in quantum physics. The strong coupling between photons and atoms may lead to light-matter hybridization, formation of polaritons, quantum entanglement and phase transitions, offering applications in quantum information science. However, photons and polaritons are normally weakly interacting with each other and have relatively large wavelengths. The practical applications, such as quantum computation, call for a strongly nonlinear regime at the nanoscale. Here, we show that a magnetically ordered material with rare-earth dopants can mimic the effects of quantum optics. Particularly, we demonstrate that antiferromagnetic orthoferrite $TbFeO_3$ exhibits ultrastrong coupling between magnons of iron spins, being analogues of photons, and the low-energy quasi-doublet states of Tb^{3+} ions, which play the role of 2-level atoms. This coupling results in magnetic phase transitions of the Jahn-Teller type.

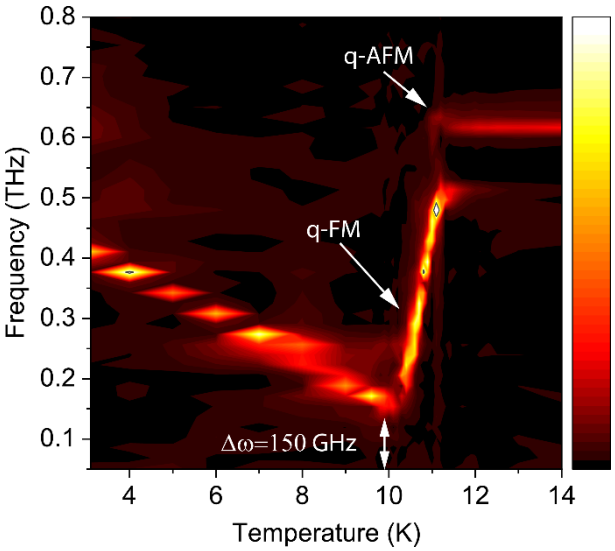

Figure 1. The map plot of the Fourier spectra as a function of the sample temperature. The abrupt change in the q-FM frequency (~11 K) indicating the spin reorientation phase transition.

This work employs ultrashort terahertz (THz) pulses to excite low-energy excitations of Fe^{3+} spins and Tb^{3+} atomic-like transitions to reveal the character of their coupling and hybridization. The magnetisation in $TbFeO_3$ mainly arises from the spins of the Fe^{3+} ions, whereas the interaction of the spins with the Tb^{3+} electronic orbitals sets the character of the magnetic configuration. The $TbFeO_3$ exhibits a second-order magnetic phase transition of the Jahn-Teller type at temperatures below 8.5 K. This spin reorientation transition (SRT) originates from the interplay between two anisotropy energies: the Tb-Fe exchange and crystalline anisotropy energies. The SRT involve rotations of both iron spins and terbium orbital moments and even leads to the emergence of a multiferroic state. Uniquely to the orthoferrite family, $TbFeO_3$ exhibits a cross-over (i.e. equality) of the frequencies of the antiferromagnetic resonance mode and atomic-like mode of Tb, which leads to their dynamical repulsion and avoided crossing effect. The coupling is so strong that the frequency of the low-lying hybrid mode is pushed to zero. Despite this unique phase diagram, the coupled dynamics of spins and rare-earth orbitals in $TbFeO_3$ have not yet been studied.

A time-resolved pump-probe measurement was performed within a 3.5-15 K temperature range around the SRT. We used a single-cycle THz pulse generated by a tilted-front optical rectification technique in a

lithium niobate crystal as an excitation stimulus. The THz-induced dynamics were traced by monitoring the transient Faraday/Kerr effects in a pump-probe setup in transmission/reflection geometry.

Figure 1 depicts an indicative map plot of the Fourier spectra of polarisation rotation, measured as a function of the sample temperature. As expected, the coexistence of two well-distinguished modes of antiferromagnetic resonance (q-AFM and q-FM) at 650 GHz and 450 GHz were observed in a high-temperature regime [1]. Since the q-FM mode is soft - its frequency decreases while the temperature is approaching the SRT (~11 K) thus, the interaction with lying low energy of the Tb^{3+} quasidoublet is increasing. Subsequent increases in the interaction lead to the mode repulsion and limit the further softening of the q-FM mode. It is a very different behaviour from those observed in other orthoferrites, TmFeO3 and ErFeO3 [2,3], featuring a macroscopically similar phase transition at higher temperatures. The minimal frequency of the q-MF mode (150 GHz), in Fig.1, indicates the interaction strength. The same behaviour was observed in our modelling. Additionally, near the phase transition temperature, the q-FM mode bandwidth widens significantly with a subsequent increase in the spectral weight. We attribute this behaviour to the strong interaction between Tb-Fe sub-systems. The interaction increases at lower temperatures, so the Tb-sub-system mainly governs the dynamics detected in the Fe-sub-lattices.

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Dynamical Instabilities of Ultracold Fermions in an Optical Cavity

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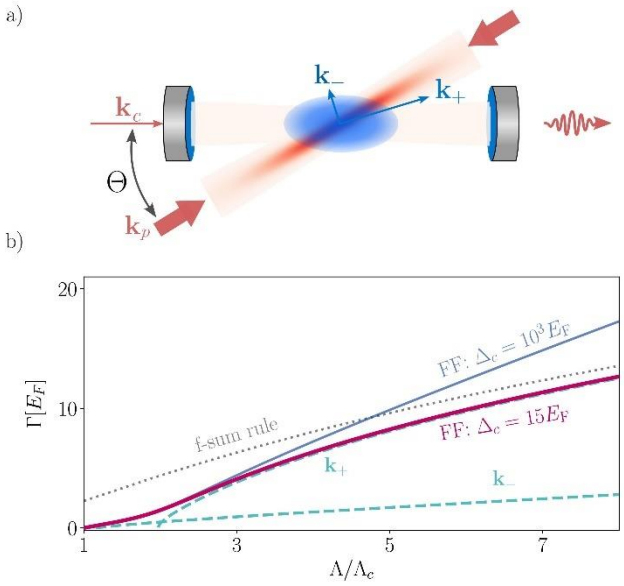
Recent observations of in vivo dynamics of ultracold fermions in an optical cavity subject to a quench of the light-matter coupling across the super-radiance transition have shed light on the instabilities that underlie the dynamics of self-organization in long-ranged interacting quantum many-body systems. Motivated by these experiments, we uncover the exponentially growing polaritonic mode associated with the instability towards self-organization. Beyond computing the rate at which density wave order and the photon population grow, we quantify the fluctuations of the pre-quench state which seed the instability. We show that our results fit existing experiments on free fermions. Furthermore, we make predictions for quench experiments involving strongly interacting fermi gases coupled to an optical cavity. Our results suggest that the non-local nature of the photon-mediated interactions between fermions produces a novel context in which the dynamics of self-organization are qualitatively different than the ordering dynamics of short-ranged interacting quantum many-body systems.



Evidence for inhomogeneous formation of photoinduced metallic domains probed by time-resolved X-ray diffraction

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Insulator-to-metal transition of VO_2 caused by the change of the structural symmetry has attracted extensive attention for many potential applications in material sciences over the last several decades. However, it remains unclear how the photoinduced phase is spatially formed and how the Peierls transition due to the formation of V-V dimers correlates with the Mott transition with the huge structural change. In this study, we are promoting the time-resolved X-ray diffraction experiments with improved the measurement efficiency by combining advanced laser and two-dimensional detector for a VO_2(80nm)/TiO_2(001) thin film to reveal the correlation between the lattice symmetry and electronics structures in the sub-nanosecond non-equilibrium states by tracking the structural transition and ordering of V-V dimers at Photon Factory, KEK.

The transient peak splitting of the (0 0 2) fundamental reflection into two peaks just after photoexcitation, as shown in Fig. 1(a), clearly indicates the inhomogeneous formation of the metallic domains with higher crystal symmetry at the low temperature condition. The melting of the V-V dimer accompanied by the formation of the metallic domain was found from the intensity modulation of the (0 -1/2 3/2) superlattice reflection shown in Fig. 1(b). The further information of the experimental results will be discussed in the presentation.

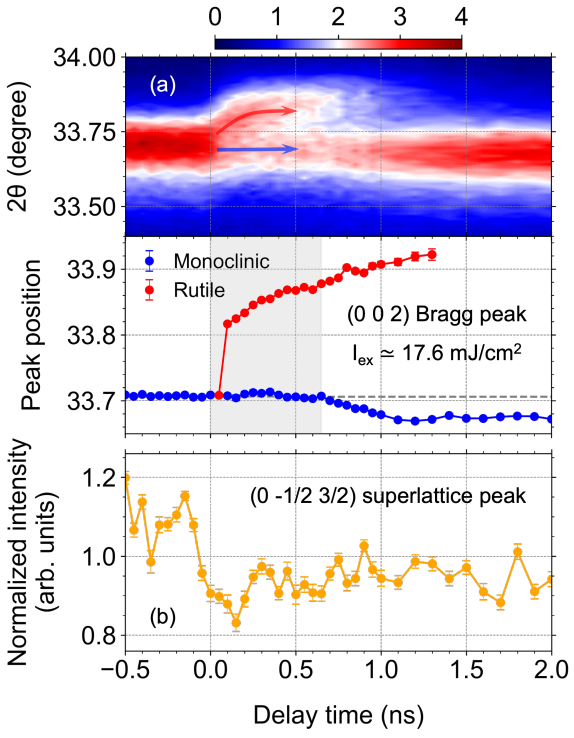

Fig. 1. (a) Time evolution of (0 0 2) diffraction angle extracted from the peak profiles and (b) intensity change of (0 -1/2 3/2) superlattice reflection.

Analysis of Strong Photoexcitations in Two-Dimensional Mott Insulators Using Singular Value Decomposition

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In weak excitation limit of the two-dimensional extended Hubbard model, it is known that excitonic peaks occur even when the inter-site Coulomb potential $V = 0$ [1,2]. This is attributed to magnetic effects arising from spin-charge coupling, indicating the significant role of spin degrees of freedom in the optical excitations of two-dimensional Mott insulators. Here we focus on the spin-charge dynamics in the *strong* optical excitations of two-dimensional Mott insulators and perform analysis using the singular value decomposition (SVD) [2].

In this study, we obtained numerical exact solutions of the time-dependent Schrödinger equation using the Hubbard model with $N = 16$ for the time-dependent many-body wavefunction $|\psi(t)\rangle = \sum_i c_i(t)|\phi_i\rangle$. By arranging the solutions at time t_l in the l-th row to form a coefficient matrix and performing the SVD, we can obtain energy eigenstates $\{|\Phi_n\rangle\}$ of the Hamiltonian without light fields contributing to the dynamics [2].

In this study, with the transfer integral denoted as T, we set the onsite Coulomb as $U/T = 10$ and assumed a dimensionless vector potential as $A(t) = A\exp[-t^2/D^2]\cos(\omega t)$ for the optical pulse. Here, A represents the amplitude, D the pulse width, and ω the optical frequency. The gap energy of this system is about $6T$. Figure 1 shows the energy spectra obtained from the SVD in the mid-gap region. The horizontal axis is the eigenenergy E_n of $|\Phi_n\rangle$ with the ground state energy is zero and the spectral intensity indicate the quantum weights of $\{|\Phi_n\rangle\}$ after the pulse off [2]. We found that spin-excited states are generated via two-photon processes at $A = 1$, $D = 0.3/T$, and $\omega/T = 13$. As A increases, the contribution of mid-gap states with $E_n/T > 1$ becomes significant. We revealed that while the state at $E_n/T \approx 1$ does not contain the component of the Neel state, the states with $E_n/T > 1$ contain the component of the Neel state. This suggests the generation of spin-excited states via different optical excitation pathways, indicating the importance of spin-charge coupling in the strong optical excitations.

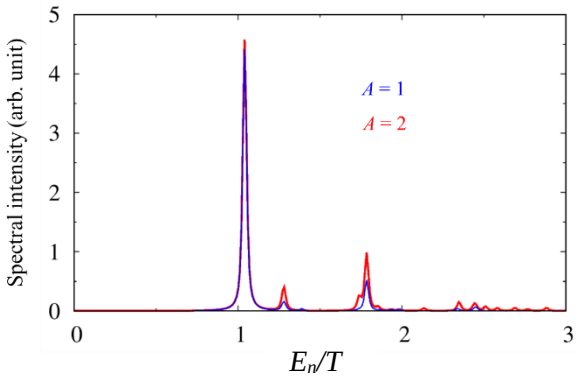

Fig. 1: Energy spectra obtained from the SVD.

[1] T. Tohyama et al., Phys. Rev. Lett. 89, 257405 (2002); [2] J. Tokimoto, S. Ohmura, A. Takahashi, K. Iwano, and H. Okamoto, Phys. Rev. B, *accepted*.

Probing Inhomogeneous Cuprate Superconductivity by Terahertz Josephson Echo Spectroscopy

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Inhomogeneities play an important role in determining the properties of quantum materials. Local probes such as scanning tunnelling microscopy have extensively reported that the electronic properties of cuprate superconductors are inhomogeneous over nanometer length scales [1]. However, such probes are often effective only far below the critical temperature T_c. Here, we develop a complementary probe of inhomogeneous superconductivity in cuprate superconductors. Namely, two-dimensional terahertz spectroscopy is used to measure Josephson plasmon echoes from an interlayer superconducting tunneling resonance. In this way, one is able to disentangle intrinsic lifetime broadening from extrinsic inhomogeneous broadening for interlayer superconducting tunnelling in near-optimally-doped $La_{1.83}Sr_{0.17}CuO_4$. We quantify inhomogeneous broadening up to $0.7T_c$, above which Josephson plasma resonance is lifetime-limited.

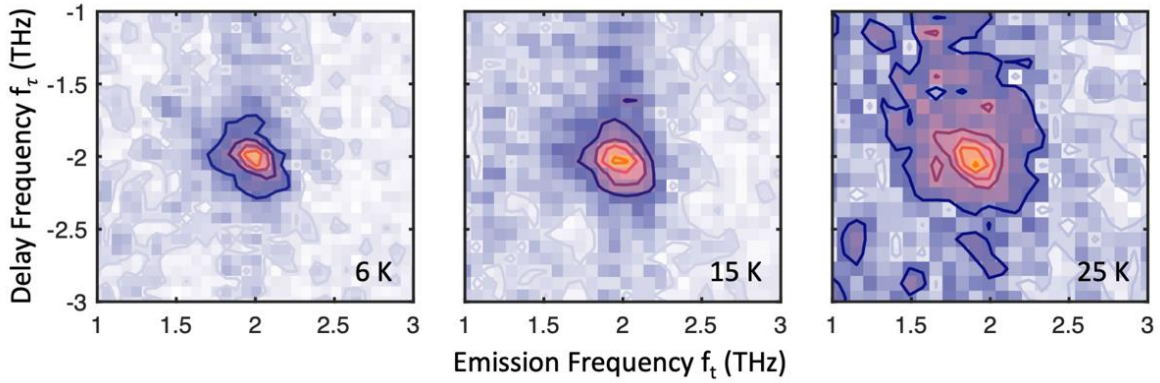

Figure: Two-dimensional Josephson echo spectra of $La_{1.83}Sr_{0.17}CuO_4$ for increasing temperatures**.** Two-dimensional spectra in the $(f_t,f_\tau) = (f_p,-f_p)$ quadrant with equal-value contours plotted on top of the raw data. 'Almond' asymmetry of the peak is clearly observed at 6 K, indicating the presence of disorder. At higher temperatures, the peak lineshape becomes increasingly symmetric due to a lesser relative importance of disorder

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INHOMOGENEOUS DISORDERING AT A PHOTOINDUCED CHARGE DENSITY WAVE TRANSITION [1]

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Using ultrashort laser pulses, it has become possible to probe the dynamics of long-range order in solids on microscopic timescales. In the conventional description of symmetry-broken phases within time-dependent Ginzburg-Landau theory, the order parameter evolves coherently, with small fluctuations along an average trajectory. Recent experiments, however, indicate that some systems can support a different scenario, named ultrafast inhomogeneous disordering, where the average order parameter is no longer representative of the state on the atomic scale. Here we theoretically show that ultrafast disordering can occur in a minimal, yet paradigmatic, model for a Peierls instability if atomic scale inhomogeneities of both the electronic structure and the charge density wave order parameter are taken into account. The latter is achieved using a nonequilibrium generalization of statistical dynamical mean-field theory coupled to stochastic differential equations for the order parameter.

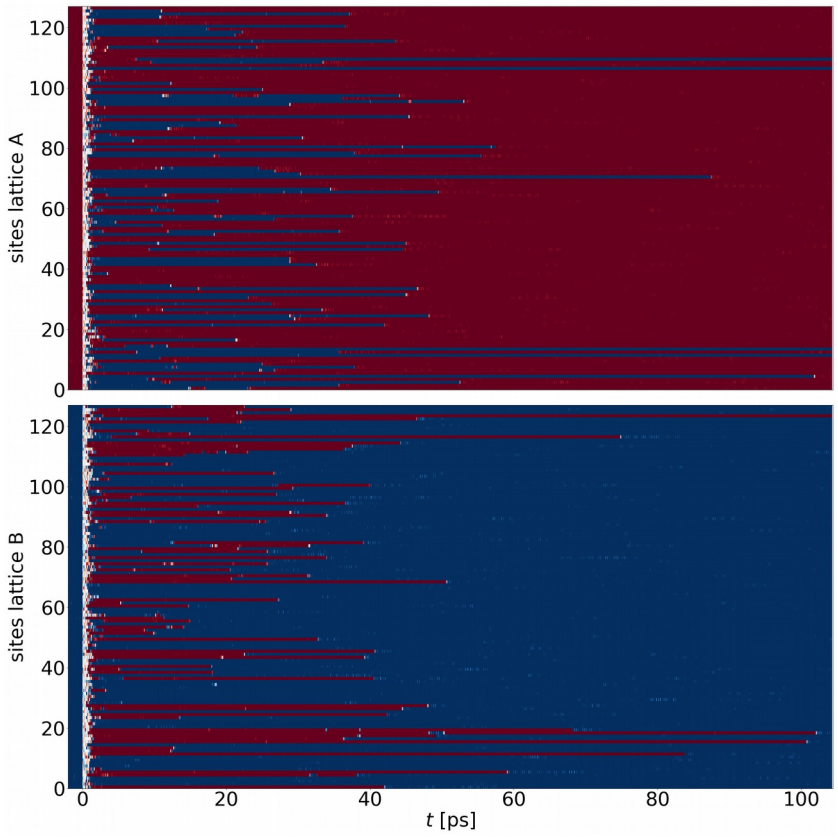

FIG. 1: Stochastic time evolution of lattice sites X_j after the photoexcitation at $t = 0$ for all trajectories.

[1] A. Picano, F. Grandi, M. Eckstein, Phys. Rev. B **107**, 245112, Editors' Suggestion.

Investigation of electron-phonon dynamics in $LaAlO_3/SrTiO_3$ heterostructures

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We investigate the nonlinear optical properties of $LaAlO_3/SrTiO_3$ (LAO/STO) heterostructures using second harmonic generation (SHG). To characterize structural symmetry, we measure azimuth- and thickness-dependent second harmonic responses of the heterostructures and observe apparent changes depending on the LAO thickness, originating from the LAO/STO interface. For the temperature-dependent second harmonic response, the evolution of the nonlinear response at below 100 K shows electron-lattice interaction coupling, which corresponds to the low-frequency phonon mode. We trace that time-dependent second harmonic response of optically stimulated LAO/STO interface by mid-infrared pulse. By collaborating with theoretical work, we discuss electron-lattice coupling and its dynamics on the two-dimensional electron gas system at the LAO/STO interface.

Anomalous Terahertz Emission in Charge-Ordered Cuprates

Maor Rosenberg[1], Daniele Nicoletti[1], Michele Buzzi[1], Michael Fechner[1], Pavel E. Dolgirev[2], Marios H. Michael[1,2], Jonathan B. Curtis[2], Eugene Demler[3], Genda Gu[4], Yiran Liu[5], Suguru Nakata[5], Bernhard Keimer[5], and Andrea Cavalleri[1,6]

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Terahertz emission is observed after impulsive optical excitation only in media in which inversion or time-reversal symmetry are broken [1]. For this reason, in centrosymmetric superconductors this phenomenon is generally not seen, unless a current bias or a magnetic field are applied. Here, we report evidence for anomalous terahertz emission in unbiased Cuprates of the $La_{2-x}Ba_xCuO_4$ [2] and $YBa_2Cu_3O_{6+x}$ family [3], in which charge order coexists with superconductivity. A sharp response at frequencies immediately below the bulk Josephson plasma resonance suggests that this radiation originates from surface Josephson plasmons [4], which are generally dark modes but appear to be coupled to the electromagnetic continuum in these materials. We attribute this activated anomalous emission to the fact that charge order breaks inversion symmetry in the out-of-plane direction and folds the plasmon dispersion curve onto the light cone [5].

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Relaxation dynamics and thermometry in optically pumped $YBa_2Cu_3O_{6+x}$ revealed by time-resolved Raman scattering

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Driving quantum materials with electromagnetic fields can generate novel phases and states away from thermal equilibrium. Signatures of light-induced superconductivity at higher temperatures far above its critical temperature have been reported in the optical spectra of underdoped $YBa_2Cu_3O_{6+x}$ after pumping with 790 nm near-infrared pulses as well as terahertz pulses resonated with infrared-active apical oxygen phonons [1]. We used time-resolved Raman spectroscopy to investigate the non-equilibrium dynamics of the apical oxygen phonon. Time dependence of the phonon population demonstrated strong electron-phonon coupling. Also, the energy of this phonon also hardened after pumping due to the smearing of Fermi surface caused by higher transient electronic temperature in this material [2].

In another recent experiment, we resonantly drive the underdoped $YBa_2Cu_3O_{6+x}$ with terahertz light pulses which focuses on the incoherent energy transfer picture of the apical oxygen phonon of the driven state and probes phonon temperature [3]. This extracted phonon temperature was compared with the estimated increase in quasiparticle temperature from previously reported terahertz optical conductivity data [4]. These temperature changes provide quantitative information on the nature of the driven state and its decay and may provide a strategy to optimize this effect.

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Linear and nonlinear spectroscopic signatures of Josephson plasmons in bilayer superconductors

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Layered superconductors like High-T_c cuprates display soft out-of-plane plasma oscillations between layers, sustained by the weak Josephson-like coupling among the superconducting sheets. These so-called Josephson plasmons have attracted wide interest in their detection and manipulation by means of different experimental protocols [1,2], but providing a unified theoretical description valid in any region of the energy-momentum space has proven hard due to the anisotropy of the systems [3].
In bilayer cuprates the Josephson plasmons display many remarkable properties in linear and nonlinear optical experiments as well as in high-energy spectroscopies like RIXS and EELS that distinguish them from other superconductors. Our work is aimed at providing an analytical theoretical framework able to describe the features of the plasma modes of such systems and that can also be used as a groundwork to explain experimental results in any range of energy and momentum [4]. We apply this formalism to provide a microscopical explanation to the unusual transverse plasma peak appearing in the real part of the optical conductivity [5], connecting its emergence to an internal Coulomb interaction between the two planes of a unit cell. Moreover, we show that recent RIXS measurements on Ca-YBCO that probe only the upper Josepshon plasmon [6] are consistent with optical experiments and they can be understood through the momentum-dependence of the polarizations of the two Josephson plasmons [7]. Finally, we expand our framework to study nonlinear phenomena like Third Harmonic Generation [8], showing that a full characterization of the plasmon dispersion is necessary to interpret the data [9].

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Coherent structural dynamics in V2O3 under hydrostatic pressure

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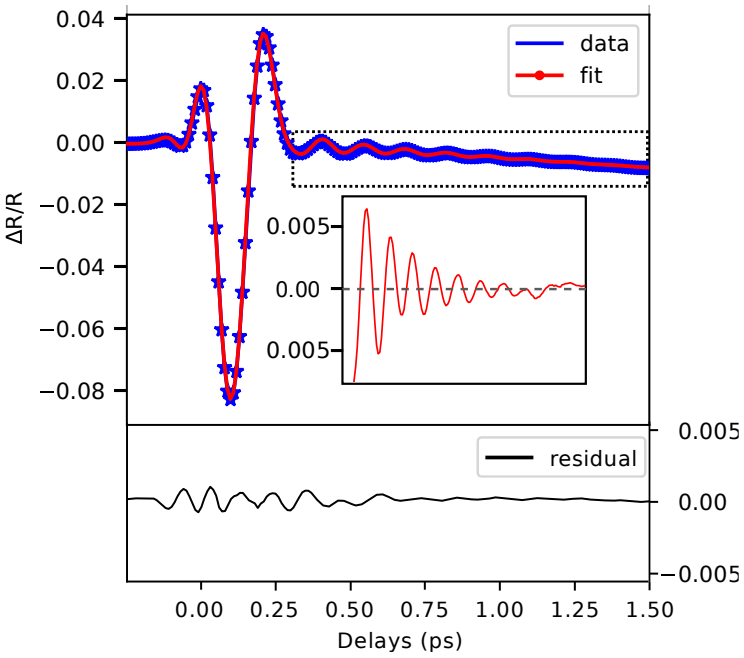
Recently, material science has moved from observing and understanding electronic and structural orders to control physical properties of materials on command by using external stimuli such as light. From this point of view, a crucial aspect is the understanding of the fundamental interactions within the system (electron-electron and electron-phonon) to control the emergent cooperative effects.
Here, we combine ultrafast optical spectroscopy and high-pressure setup to monitor the out-of-equilibirum dynamics of the material under well-defined controlled thermodynamical environnement.
The obtained results demonstrate the use of spectroscopy of coherent phonon as a thermodynamical phase marker of the Insulator to Metal Transition in V2O3 thin film. More intriguing, the variation of frequency of the observed phonon optical mode (A1g) seems to reflect the manifestation of critical coupling between lattice and electronic degrees of freedom near transition line with a drop of frequency near the critical pressure.



Transient reflectivity of V_2O_3 thin film around
675 nm after photo-excitation with 800 nm pulse at 6200 bars

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All-dielectric metasurface for THz control of spins in ferrimagnetic Bismuth doped Gadolinium iron garnet

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We report that the coupling efficiency of terahertz electromagnetic fields to spins in a ferrimagnetic iron garnet film can be boosted by structuring the surface with a non-magnetic substrate, effectively creating a 2D metasurface. Particularly, we have identified the optimal dimensions of the two- dimensional metasurface in the form of stripes by simulations. We verified the amplification of a ferrimagnetic spin resonance by performing terahertz pump – optical and SHG probe spectroscopy. We reveal the presence of an out-of-plane terahertz magnetic field component created by the metasurface at the fundamental and first overtone frequency of the ferrimagnetic spin resonance.

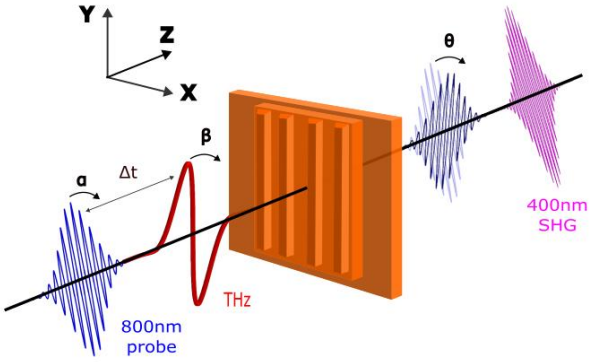

Figure: Experimental setup schematic.

Picosecond nonlinear transport in optically driven K_3C_{60}

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A number of recent experiments have shown that optically driven K_3C_{60} at temperatures above the equilibrium T_c exhibits superconducting features in the optical conductivity [1-4]. To prove and characterize the transient electrical response of optically driven K_3C_{60} at frequencies below 1 THz, we combined photoconductive switches, coplanar waveguides and doped fulleride thin films [5]. We report unique signatures of photo-induced superconductivity as nonlinear I-V characteristics in the transient state. We observe that the photo-induced state saturates into a non-equilibrium state with both linear and nonlinear transport properties similar to those observed in equilibrium for T ~ 0.8 T_c. The dynamics observed are not identical to those reported for the powder samples studied with mid-infrared excitation [1-3], however they provide valuable new information on the nature of the light-induced superconducting-like state above equilibrium T_c.

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Magnetic field expulsion in optically driven $YBa_2Cu_3O_{6.48}$

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The two distinctive features of superconductivity are the appearance of dissipationless transport and the expulsion of a statically applied magnetic field, a phenomenon known as Meissner effect. In recent studies, coherent optical excitation of certain phonon modes in $YBa_2Cu_3O_{6+x}$ has been shown to induce a transient state with superconducting-like optical properties at temperatures higher than the equilibrium T_c. While these experiments provide evidence of transient dissipationless transport, the magnetic properties of this transient superconducting-like state are still unexplored. Here, we make use of an ultrafast optical magnetometry technique to measure changes in the magnetic field in the vicinity of a $YBa_2Cu_3O_{6.48}$ sample with $\sim 1\ \mu T$ sensitivity and sub-picosecond time resolution. We provide evidence that, under the same excitation conditions that generate a transient superconducting-like state in this material, a prompt expulsion of a statically applied magnetic field ensues, a response indicative of the appearance of an ultrafast Meissner effect. We investigate how this magnetic field expulsion depends on temperature and external magnetic field, providing new insights in the magnetic properties of this non-equilibrium state.

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Single-Shot Electro-Optic Sampling for non-linear THz spectroscopy in high-Tc cuprates

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In recent years, THz spectroscopies have been used to reveal the microscopics of equilibrium and non-equilibrium phenomena in quantum materials. These experiments involve the detection of the electric field of a THz pulse, after interaction with the sample. Typically, this involves overlapping the THz pulse with a time-delayed near-infrared gate pulse in an electro-optic sampling crystal. The time-delay between these pulses is varied sequentially to reconstruct the full THz electric field trace. This mode of operation often requires long data acquisition times as a mechanical delay line has to be moved to change the THz-gate delay. Recently, it has been proposed that spatial encoding techniques can speed up this process up to approximately an order of magnitude [1]. This technique has proven its power in several experiments, yet so far, no implementation used it to sample THz transients with frequency content above 2 THz. Here, we implement such a single-shot scheme to sample THz pulses generated from optical rectification in GaP that have a spectral content up to 7 THz. Combining experimental results from this optical setup and wave-optics simulations, we aim at understanding applicability of spatial-encoding techniques in sampling higher THz frequencies. In contrast to previous implementations, our setup is built around an off-the-shelf grating, does not require custom optics to be manufactured and allows for sampling of higher THz frequencies with significant speed-up. To achieve this, care must be taken to mitigate the effect of angular dispersion on the gate beam profile with respect to the THz beam. Future experiments on the non-linear THz response of phonon-driven cuprates will benefit from the data acquisition speed-up offered by this technique.

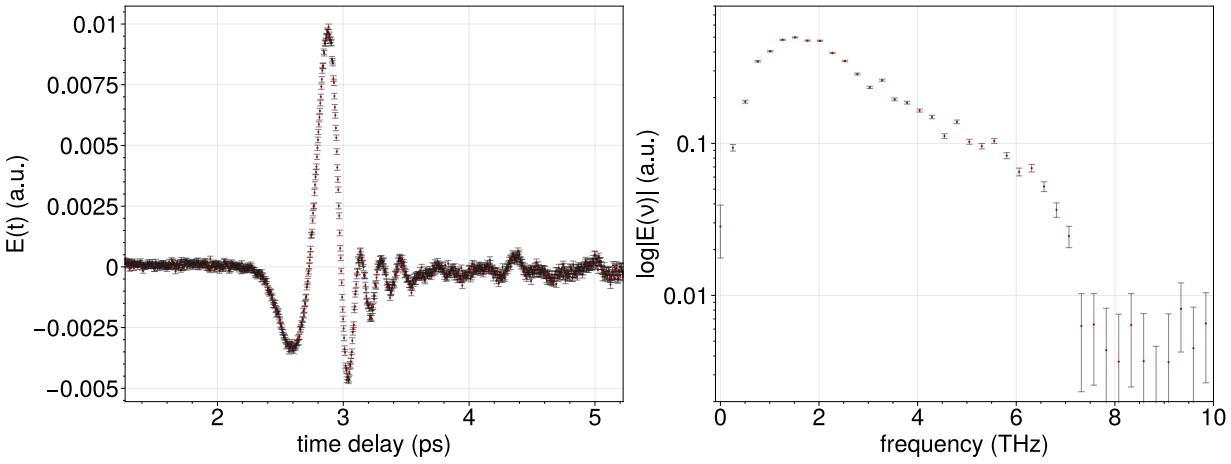

Fig. 1: (left panel) THz electric field trace measured in roughly 1 second after averaging 2000 gate laser pulse. **(right panel)** Corresponding Fourier transform showing that the technique is capable of sampling pulses with frequency content up to 7 THz.

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Resonantly Enhanced Photo-induced Superconductivity in K_3C_{60}

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Terahertz and mid-infrared light pulses can activate phase transitions in quantum materials, and create unique states that are not stable in equilibrium. In K_3C_{60}, a metastable superconducting-like state has been observed far above T_c after pumping with mid-infrared pulses [1], as evidenced by superconducting-like optical properties [1,2], nonlinear current behavior [3], and pressure dependence measurements [4].

Here, we found a two-orders-of-magnitude increase of photo-susceptibility near 10 THz pump frequency, allowing the observation of metastable superconducting-like features with a pump fluence as low as 0.4 mJ/cm^2, and for the first time up to room temperature [5]. These findings identify 10 THz as an important energy scale for the formation of the light-induced superconducting-like state in K_3C_{60}, and also pave the way towards steady-state operation, which is currently limited by the lack of a high-repetition-rate optical source at this frequency. As a first step towards such operation, we are currently carrying out experiments in which we pump K_3C_{60} sequentially with two 10 THz pulses, whilst probing the THz-frequency optical properties.

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