PROJECT FINAL REPORT

Grant Agreement number	280555
Project acronym:	GO FAST
Project title:	"Governing ultrafast the conductivity of correlated materials"
Funding Scheme:	Collaborative project
Date of latest version of Annex I against which the assessment will be made:	23/09/2014
Periodic report:	1st □ 2nd x 3rd □ 4th □
Period covered:	**From** 01-10-2013 **to** 31-03-2015
Name, title and organisation of the scientific representative of the project's coordinator[1]:	Prof. Michele Fabrizio SCUOLA INTERNAZIONALE SUPERIORE DI STUDI AVANZATI via Bonomea, 265 34136 Trieste ITALY
Tel:	+39 040 3787457
Fax:	+39 040 3787 528
E-mail:	fabrizio@sissa.it
Project website[2] address:	http://www.gofastproject.eu/

[1] Usually the contact person of the coordinator as specified in Art. 8.1. of the Grant Agreement.
[2] The home page of the website should contain the generic European flag and the FP7 logo which are available in electronic format at the Europa website (logo of the European flag: http://europa.eu/abc/symbols/emblem/index_en.htm logo of the 7th FP: http://ec.europa.eu/research/fp7/index_en.cfm?pg=logos). The area of activity of the project should also be mentioned.

Table of summary

4.1. Final publishable summary report

4.1.1. Executive summary

The GO FAST project, launched the 1st April 2012, officially ended the 31st March 2015. The results were presented in Brussels the 10-11 March 2015, at the EC premises in occasion of the Cluster Review of three femtodynamics projects GO FAST, CRONOS and FEMTOSPIN, funded under the NMP.2011.2.1-2 topic Modelling of ultrafast dynamics in materials.
The aim of this research project was to develop novel schemes to study electronic, optical and structural properties of correlated materials driven out of equilibrium, in view of achieving an ultrafast optical control of their electronic properties. In particular, the most advanced theoretical techniques for correlated systems have been extended, i.e. Dynamical Mean Field Theory (DMFT) and the Gutzwiller variational approach, to model the temporal evolution after high-energy excitations are impulsively photoinjected by ultrafast laser pulses.
Realistic modelling was achieved through validation against the outcomes of different ad-hoc time-resolved experimental techniques. The possibility to optically switch on and off the metallic phase in a model Mott insulator (vanadium sesquioxide) and the superconducting phase in model high-temperature superconductors (BISCCO) have been investigated and tested.
The mutual and effective collaboration between the theoretical and experimental groups ensured the skill and the expertise needed to develop and validate realistic models of the ultrafast dynamics in complex materials, where the electronic, structural and magnetic degrees of freedom are strongly intertwined. The important achievements of the project are testified by the number of publications in high impact factor journals: 44 articles of which 4 published in Nature journals, 4 in Physical Review Letters, 2 in Scientific Reports, 15 in Physical Review B, and an invited review in Advanced in Physics, to appear in 2015.
GO FAST was funded with EUR 1,673,200.00 (one million six hundred and seventy three thousand two hundred EURO) granted by the European Commission in the 7th Framework Programme, coordinated by Prof. Michele Fabrizio of the Scuola Internazionale di Studi Superiori Avanzati – SISSA (Italy), and carried out by a consortium of 7 leading research institutions of four different Countries, each of them with specific roles and different levels of involvement. The project was carried out under supervision of the EU Project Officer (PO) Anne De Baas and of the Project Technical Advisor (PTA) Richard Ball. For more information on the project, please go to www.gofastproject.eu.

4.1.2. Project context and the main objectives

Over the last decade, impressive experimental progresses made it possible to access the early temporal (femtoseconds to picoseconds) evolution of materials driven out of equilibrium by ultra-short laser pulses. Such technology was believed to have two major potentials: it could represent a tool to investigate dynamics directly in the time domain and much beyond the linear response regime, thus providing relevant physical information otherwise inaccessible; it might

allow changing material properties much faster than usual and studying their properties along the way.
Among the materials these novel experimental tools were most frequently applied to, correlated transition metal compounds had a prominent role. These materials display incredibly rich phase diagrams, where even a tiny change of pressure, temperature, chemical composition or other external perturbations can drive a transition between completely different phases. Such noteworthy property when faced with conventional semiconductors makes correlated materials promising candidates for “phase-change” ultrafast devices. In addition, one may even foreshadow that these compounds, just because of their wealth of phases, could be driven by a sudden perturbation into transient metastable phases not present in the equilibrium phase diagram, a potentially exciting scenario. Time-resolved femtosecond spectroscopy was just the right tool to study correlated materials along the way of an electric-field-driven or optically driven phase-change, and assess all their potentials.

The GO FAST project started when this new field was just to explode, with leading experimental and theoretical groups localized mostly in Europe. The purpose was to assemble together a strong team with complementary expertise to understand the physics of ultrafast photo-excited correlated materials better than what each member could individually achieve. In other words, GO FAST aimed at steering theoretical and experimental efforts from different places all over Europe towards a single and shared target, thus increasing the probability of successful achievements.

In particular, the project focused on two representative compounds: vanadium sesquioxide (V_2O_3), likely the first Mott insulator ever discovered back in 1960, and copper-oxide superconductors in the BISCCO family, the materials that 30 years ago piqued the interest of the scientific community in strong correlations. V_2O_3 was chosen as representative of Mott insulator transition metal oxides with a *d-d* charge gap, while cuprates as representatives of charge-transfer Mott insulators. The goal was to explore experimentally and model theoretically their non-equilibrium phase diagrams to ascertain whether intense and ultra short laser pulses indeed allow driving phase-changes faster than by usual means, e.g. rising temperature or pressure, and studying their non-equilibrium dynamics. Particular emphasis was placed to photoinduced transitions of technological interest, specifically between phases with completely different conducting properties, Mott insulating versus metallic/superconducting, with the objective of identifying non-equilibrium pathways between them, i.e. the external parameters that can be tailored to drive more efficiently those transitions (laser frequency, polarization and incidence angle, or sample thickness).

To achieve these goals, a multidisciplinary network was organized comprising the condensed-matter theory group at SISSA (Trieste), with expertise in strongly correlated systems, and well established European experimental groups in the field of ultrafast spectroscopies, with expertise in time-resolved optical and photoemission spectroscopies, time resolved X-ray and electron diffraction. The theoretical task undertaken by SISSA was to develop and refine tools for studying models of correlated materials in out-of-equilibrium conditions, and apply those methods to simulate realistic situations. Inputs and feedbacks from experiments performed by the other partners were mandatory to validate modeling and results, and to better orient the

theoretical activity. Such a symbiotic effort by theoretical and experimental groups has been the fingerprint and key of success of the project.

4.1.3. Description of the main S&T results/foregrounds

Major Scientific Results (MSA)

Among the many fundamental scientific results obtained within the GOFAST consortium, we summarize here the most relevant innovative aspects, which are grouped into three Major Scientific Achievements (MSA):

MSA1 Out-of-equilibrium Gutzwiller method

The development of an efficient and flexible scheme to simulate the non-equilibrium dynamics of lattice models for correlated electron systems based on the Gutzwiller variational wavefunction and approximation. This method is exceptionally fast and efficient while providing results in accordance with much more expensive rigorous techniques.

MSA2 First-order insulator-to-metal phase transition

In the course of the project, it has become clear to us and to the whole scientific community that the gap between the lower and the upper Hubbard bands in Mott insulators is as robust as the gap in conventional band insulators. Therefore, despite early expectations, the gap between Hubbard sidebands cannot be collapsed down; hence the “metallic” carrier density of Mott insulators cannot be made available by electric or light-driven breakdown. On the contrary, a feature that really differentiates Mott from band insulators is that a Mott transition is generically first order so that, within the coexistence region on the insulating side of that transition there exists a metastable metal phase besides the stable insulating one. One can thus imagine driving the insulator into the metastable metal phase. Thanks to the knowledge developed within the GO-FAST project, we have been among the first to propose that this remarkable physics requires internal degrees of freedom not present in the simple single band Hubbard model, but common to most known narrow-gap Mott insulators. The main issue in this context is to identify the extensive variable *M* that controls the first order transition (the equivalent of the volume in the liquid-vapour phase transition) and the optical excitation channel, if any, that can change *M* from its equilibrium value. We have accomplished this program in a model mimicking V_2O_3, and shown that such a non-equilibrium trapping into a metastable metal phase can be realized. We also performed a pump-probe time-resolved photoemission experiment on V_2O_3, and found that indeed the gap collapses down and recovers back on time scales of few picoseconds, much longer than typical electronic relaxation times but not unrealistic for the time a nucleus of a wrong phase would take to dissolve within the coexistence region of a first order phase transition. We have indirect support that the mechanism underneath the observed gap-collapse is the predicted one by the evidence of photo-induced phonon hardening in V_2O_3 and its critical dependence upon laser polarization and incidence geometry.

MSA3 Non-thermal ultrafast effects in superconducting copper oxides

Copper-oxide high-T_c superconductors are one of the most interesting class of materials. The superconducting temperature exceeding the liquid nitrogen opens important routes towards the all-optical control of the superconducting-to-normal phase transition. In particular, the possibility of optically switching on and off a superconducting phase would have a dramatic impact in the field of ultrafast electronics and THz devices. The major complexity in modelling the ultrafast radiation-matter interaction is the strong **k**-space anisotropy of the physical properties of copper oxides, which is inherently related to the strong short-range coulomb repulsion between the charges in the CuO_2 plane. Within the GOFAST project, we were able to develop the basic model to capture the intrinsic dichotomy of the excitations photo-injected with wavevectors parallel to or at 45° with respect to the Cu-O bonds. We demonstrated that the non-equilibrium population that is created in the first femtoseconds has a strongly non-thermal character both in the **k**- and energy-distribution. These findings pave the way to optical-control the state of superconducting cuprates in a novel fashion, which goes beyond the simple tuning of the temperature of the system.

We summarize here two major outcomes of the joint theoretical-experimental efforts carried out during the project. First, by combining modelling, femto-ARPES and time-resolved spectroscopy, we have demonstrated that the optical excitations of doped cuprates induces a non-thermal overpopulation of anti-nodal states, characterized by a lifetime longer than that in equilibrium conditions. In simple terms, at specific doping concentrations and low temperature, the photo-excitation creates a transient conducting state that cannot be achieved in equilibrium conditions.

Secondly, cuprates are inherently particle-hole asymmetric. For example, in the simplest case of the undoped compounds that are typical charge-transfer insulators, the photo-doped holes go to the oxygen atoms while the electrons to copper atoms. In such a situation one can envisage that the optical excitation may appreciably alter the chemical potential and effectively dope the material. We have indeed discovered such a remarkable effect by time-resolved femto-ARPES on $Bi_2Sr_2CaCu_2O_{8+\delta}$. The above experimental observation could represent a real breakthrough since it opens the possibility of transiently photodoping the system and entering a superconducting phase in a non-thermal fashion.

Key Exploitable Results

During the project, the consortium had the opportunity to cooperate with a consultant belonging to the Exploitation Strategy and Innovation **Consultants** (ESIC) Agency. The Exploitation Strategy Seminar (ESS), help in SISSA, was very helpful to identify, within the Major Scientific Achievements, the Key Exploitable Results (KERs), listed in the Table below, which comprise: (1) practical side-products (specifically a new software and the design of a 3D cryostat managing tool); and (2) theoretical results in terms of methods and theoretical concepts.

Table of KERs

No.	WP of ORIGIN	MSA	TYPE	COMMENT	RESPONSIBLE	PARTNER
1	4	3	method	METHOD of photodoping and its application to transistor-like devices	Uwe/ Ping Zhou	UDE
2	1	1	method	METHOD to study out-of-equilibrium models	Michele Fabrizio	SISSA
3	1	3	code	CODE to implement the time dependent dynamical mean theory t-DMFT	Michele Fabrizio	SISSA
4	3	2	theory	THEORY on the reasons why the Mott gap collapses for several ps after an ultra short laser pulse	Michele Fabrizio	SISSA
5	1	3	code	CODE for the analysis of pump-probe THz spectroscopy experiments	Claudio Giannetti	UNICATT
6	1	3	code	CODE for the dynamics of the order parameter in a symmetry-broken phase	Claudio Giannetti	UNICATT
7	1	3	tool	DESIGN of 3D cryostat managing system – by PRODUCT	Claudio Giannetti	UNICATT

The KERs, listed in Table, have been divided into three groups:
a) CODE related issues (KER 3,5,6)
b) THEORY/METHODS related issues (KER 1,2,4)
c) Product model related issues (KER 7)

The GO FAST scientific review

The GO FAST review has been carried out in Brussels, at the presence of the project officer (PO), of the project technical advisor (PTA) and of the reviewer Eric Wimmer.
The result of the review has been presented in a report produced by the reviewer. According to the report, the researchers of the GO FAST team have produced a number of high-profile publications and conference contributions. It has to be said that the area of strongly correlated systems is still in a research phase rather than being close to industrial applications. Software developments have been carried out within existing simulation platforms, especially Quantum Espresso, Continuous-time quantum Monte Carlo (CT-QMC), the Toolbox for Research on Interacting Quantum Systems (TRIQS), and Wien2k (Wien2dynamics). Except Wien2k all of the above codes are licensed under GPL. During the project new modules for the multi-physics software COMSOL have been developed. The GO FAST project has also paved the way for future code developments such as a time-dependent dynamical mean-field theory (t-DMFT) code that could be joined with existing programs such as Quantum Espresso.
The GO FAST project had a significant experimental component and interesting exploitable side-products have emerged from this activity, including the modelling of THz pump-probe experiments (Menlo Systems, a German spin-off from the Max-Planck-Institute for Quantum Optics) and the development of a low-vibration mechanical handling system for a closed-cycle cryostat (5Pascal, an Italian vacuum and cryogenic systems company; ARSCryo, a US company for cryogenic systems). Menlo Systems is looking out for new laser materials, but does not envisage to adopt the modelling developed. It is thus concluded that GO FAST was set-up and remained a rather academic project with exploitation potentials only in the far future. The reached TRL is judged to be 2.

Description of the MSA and related KERs

MSA1 Out-of-equilibrium Gutzwiller method

The MSA1 relates to a method that has been developed by GO FAST to approximate the out-of-equilibrium time-evolution of lattice models for correlated electrons. This Major Scientific Achievement is also reputed one of the Key Exploitable Results, indeed KER2 in the Table above. We present the method in detail in what follows.

KER2: METHOD to study out-of-equilibrium models

Correlated materials are difficult to model by all methods based on independent particle schemes, like DFT in local or semi-local approximations or Hartree-Fock. The reason is that the Mott's localization characterizing these systems is a collective phenomenon, which evidently escapes any representation in terms of independent particles. Over the years, several ad-hoc techniques have been developed to deal with strong correlations. The most rigorous are also the most numerically demanding, like Variational or Quantum Monte Carlo, exact diagonalization, Density Matrix Renormalization Group, or Dynamical Mean Field Theory (DMFT). In the late 1960 Martin Gutzwiller proposed a very simple variational wavefunction for strongly correlated systems and an approximation to calculate average values on that wavefunction, which were named Gutzwiller wavefunction and approximation after him. The Gutzwiller wavefunctions consists of a variational Slater determinant that is modified by the action of variational linear operators, one at each site, whose role is to reduce the weights of

local configurations that cost too much repulsive energy. This class of wavefunctions is broader than that of the Hartree-Fock mean-field theory, which includes only Slater determinants, hence it is variationally more accurate.

The Gutzwiller approximation, which later was found to become exact in the limit of infinite coordination lattices, allowed to uncover over the years many basic and popular concepts in the physics of strongly correlated systems, like the Brinkman-Rice description of the Mott transition, or the RVB scenario for High-T_c superconductivity. In reality, one may regard the results of the Gutzwiller approximation as the limiting expression of the results obtained in finite-coordination lattices by Jastrow variational wavefunctions when the lattice coordination tends to infinity. Since Jastrow wavefunctions are known to describe very accurately correlated systems, the Gutzwiller approximation is believed to provide sensible results also when used in finite-coordination lattices; the Mott's physics is local hence there should not be sensible differences between e.g. a cubic lattice and a hypercubic one in infinite dimensions.

It is well known that the variational principle can be generalized also in the time domain, where, instead of minimizing the total energy, one has to extremize an action defined by the integral over time of the average value of the Schrödinger equation, the so-called Dirac-Frenkel variational principle. We have shown that a generalized Gutzwiller approximation allows working out analytically the time-dependent variational principle for Gutzwiller wavefunctions in infinite coordination lattices. This result is far from being trivial. Indeed, the Gutzwiller approximation relies on a self-consistency condition that, in the temporal evolution, should be enforced at any instant of time, a constrained time-evolution extremely hard to implement. We found that a proper extension of the class of Gutzwiller wavefunctions still manageable analytically leads to the remarkable result that, if the self-consistency condition is satisfied at the initial time, it will remain fulfilled at any subsequent time without requiring any constraint on the dynamics. This makes our time-dependent Gutzwiller approximation method exceptionally fast and efficient while providing results in accordance with much more expensive rigorous techniques, like time-dependent DMFT. We have described the method in a monograph appeared in the book *"New Materials for Thermoelectric Applications: Theory and Experiments",* NATO Science for Peace and Security Series B: Physics and Biophysics 2013, pp. 247-273, published by Springer, see http://link.springer.com/chapter/10.1007/978-94-007-4984-9_16 and downloaded 748 times so far. We were also invited to present the method at the APS 2015 March Meeting held in San Antonio, one of the most prestigious condensed-matter conferences worldwide.

The method is relatively easy to implement; one just needs some clever routine to integrate first-order non-linear differential equations, plenty of which are freely available in open source numerical libraries. Therefore we believed not worthy exploiting the method by a software tool. The important result here was the method itself, rather than its implementation in a code.

In fact, the method has the nice feature that it can describe on equal footing both the dynamics of quasiparticles, i.e. the variational parameters of the Slater determinant, as well as the dynamics of the Hubbard sidebands, represented by the variational parameters of the local linear operators. These two sets of degrees of freedom are coupled to each other in a mean-field fashion, i.e. each evolves in a time-dependent potential generated by the other. Such limitation implies that the method cannot describe a full relaxation to a steady state. However

the values of time-integrated observables compare well with those obtained by more expensive rigorous tools, like the time-dependent DMFT, see the figure.

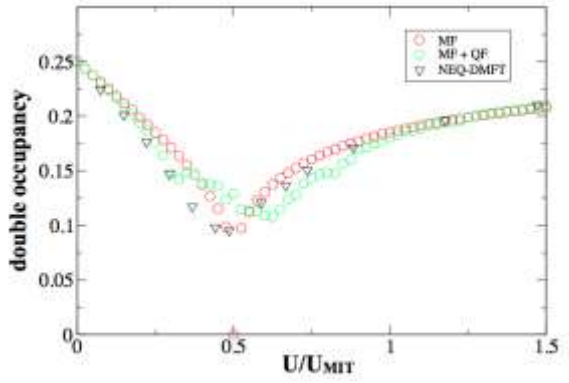


Figure 1 - Time-integrated value of the double occupancy in the single-band Hubbard model at half-filling after a sudden interaction quench from U=0 to U in the abscissa, here measured in units of the Mott transition value U_{MIT}. MF and MF+QF stand for the Gutzwiller approximation without or with leading quantum fluctuations, while NEQ-DMFT are the results of time-dependent DMFT.

In the figure the cusp at U = 0.5 U_{MIT} signals within the time-dependent Gutzwiller approximation (t-GA) the dynamical counterpart of the Mott transition, which is accessible because t-GA can afford long simulation times unlike time-dependent DMFT, a great advantage with respect to the latter that partly compensate the minor accuracy.

Within the GO FAST project we have applied the t-GA to a variety of relevant case studies. For instance we have found that the surface dead layer with poor metallic behaviour that appears at the surface of a correlated metal can be driven dynamically in a Mott insulator, the dynamical counterpart of a surface Mott transition, by the analogous of a photo-excitation of the surface layers.

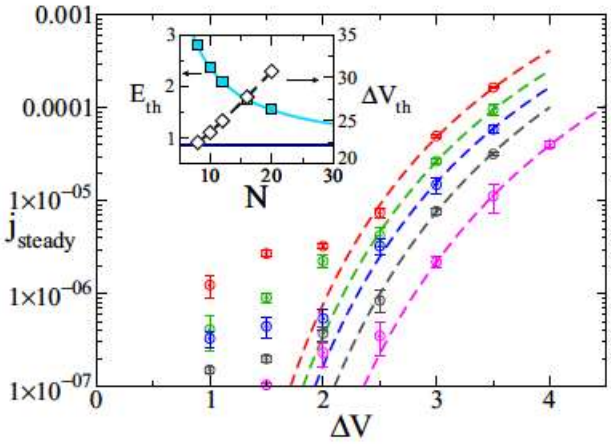


Figure 2 - I-V characteristic of a Mott insulating slab described by the single-band Hubbard model at U=16.5 with increasing size, N= 8, 10, 12, 16 and 20 from top to bottom. The dashed lines are fitting curves with $J = \gamma\ \Delta V \exp(-E_{th}/E)$, where the threshold electric field is shown in the inset as function of the size N, and γ is a fitting parameter. In the inset the solid line is the extrapolated field for N = ∞.

More recently we have studied in detail by t-GA the dynamical properties of a correlated slab in different non-equilibrium conditions. For instance we have investigated the dielectric breakdown of a Mott insulating slab in the presence of an applied electric field and found that it occurs exactly as in conventional semiconductors by Landau-Zener tunnelling across lower and upper Hubbard bands, see the figure above. This also implies that the threshold field $E_{th} \approx E_{GAP}/\xi$, where E_{GAP} is the Mott gap and ξ the insulating correlation length.

Another methodology achievement obtained within GO FAST has been the extension at finite temperature of the Gutzwiller approximation. The variational principle at finite temperature states that the actual free-energy is the absolute minimum of the functional $F(\rho) = Tr(\rho H) - T$

S(ρ), where ρ is a density matrix probability distribution, H the Hamiltonian, and S(ρ) = - Tr(ρ lnρ) the Von Neumann entropy of the distribution. Evidently, if one limits the search within a subset of density matrices ρ, one obtains an upper estimate of the actual free energy. Exploiting mathematical trace inequalities, we have been able to find a simple analytic expression that provides an upper estimate of the free energy functional for Gutzwiller-type density matrices. This allows explicitly calculating a variational free energy within the Gutzwiller approximation, hence phase diagrams at finite temperature. The comparison with more rigorous DMFT is quite satisfactory.

In the future it will be important to extend the time-dependent Gutzwiller approximation at finite temperature, in order to obtain more realistic results. In addition, in view of recent successful attempts to combine DFT-LDA+U with the Gutzwiller approximation, it would be of interest to extend such tool at finite temperature, which could allow describing by first principles Mott insulators that are not accompanied by any symmetry breaking, like in V2O3 above the Nèel temperature. In addition, it might be worth exploring the possibility to join time-dependent DFT (TDDFT) with t-GA, which could describe accurately the early time evolution of a correlated material in view of the next generation of attosecond time-resolved spectroscopies.

MSA2 First-order Mott insulator-to-metal phase transition

This theoretical result was actually achieved in the last year of GO FAST and stimulated by very recent exciting experiments and by the awareness that theoretical modelling was missing some crucial fact and thus could not explain the experimental data. We hereafter discuss thoroughly the theory that we developed and that we consider a key exploitable result, KER4 in the list.

KER4: THEORY on the reasons why the Mott gap collapses for several ps after an ultra-short laser pulse.

Mott insulators are “unsuccessful metals” where electron motion is impeded by strong Coulomb repulsion. Their use in microelectronics started to be seriously considered in the 1990s, when first reports of field-effect switches appeared. These attempts were motivated by the expectation that the dielectric breakdown in Mott insulators, which have metallic-like electron density, could all of a sudden release all formerly localized carriers, a significant potential for nanometer scaling. This was the general belief when GO FAST started. However, experiments on hard gap Mott insulators, like Ni or Cu oxides, as well as theoretical results have partly failed to meet such expectation. For instance we, as well as other groups worldwide, have shown that the dielectric breakdown of a simple Mott insulator described by the single-band Hubbard model occur via Landau-Zener tunneling across lower and upper Hubbard bands, as if the latter were as rigid as valence and conduction bands in semiconductors. We have also shown that excitations across the preformed Mott-gap drive correlated metals towards a Mott insulating phase, rather then making them more metallic. In addition, a photo-doped single-band Mott insulator, with holes in the lower Hubbard band and electrons in the upper one, appears qualitatively close to a regular photo-doped semiconductor: the gap is essentially unaffected and the mobile carriers are just the poorly coherent photo-injected holes and electrons.

However, noteworthy experimental discoveries on narrow-gap Mott insulators, which intervened over the very last years, have changed this state of affairs and suggested that the conventional portrait of a Mott transition was overlooking some crucial elements. These experiments have actually materialized the original expectation showing that narrow-gap Mott insulators can be driven out-of-equilibrium in metal phases that last anomalously long time, and, furthermore, that such phase change does not require strong electric fields or intense laser pulses, i.e. comparable with the Mott gap.

We have paid lot of efforts during the last year of GO FAST to understand what theoretical modeling was missing, and we believe we finally got an answer that actually opens very interesting conceptual and practical perspectives. We started from observing that all known Mott transitions are strongly first order, which entails an extended metal-insulator coexistence. Traditionally, the first order nature has been considered as accidental and secondary at best in most present discussions of equilibrium and especially non-equilibrium metal-insulator transitions. Instead we now believe that this is just the key to rationalize the experiments: it is not the Mott insulator that is continuously turned into a metal by the external perturbation, but it is a totally different metal phase that emerges, which was only metastable at equilibrium. The other observation that guided our analysis was that the gap had to be different from that between lower and upper Hubbard bands. In fact, in the latter case the behavior should be similar to a single-band Hubbard model, which we mentioned behaves just like a normal semiconductor. Remarkably, in all known Mott insulators the gap is never the one between lower and upper Hubbard bands. In fact it is either a charge-transfer gap or a gap between occupied and unoccupied *d*-orbitals.

In conclusion, our working hypotheses were: (1) a strong first-order Mott transition; (2) a gap different from that between lower and upper Hubbard bands. We argued that both (1) and (2) are actually manifestation of the same physics. While the main drive to the metal-insulator transition is electron repulsion, on the way to Mott's localization other mechanisms come into play and contaminate the otherwise ideal Mott transition. Magnetism is the best-known example, but not the only one. For instance, the coupling to the lattice, which controls the crystal field and the degree of bonds covalency, and the Coulomb exchange splitting, responsible of Hund's rules, are other major actors. It is not difficult to realize that these new actors support and boost the first order character of the Mott transition and as well they open a gap that is not the one, already preformed and much bigger, between lower and upper Hubbard bands. We disclosed this scenario in a toy-model for V_2O_3, which consists of two orbitals split by a crystal field with a density of one electron per site. In this model the Mott insulator describes an empty higher orbital and a half-filled lower one, which is Mott localized and antiferromagnetically ordered. Its phase diagram obtained by the Gutzwiller approximation at finite temperature is shown in the figure, in comparison with that of V_2O_3.

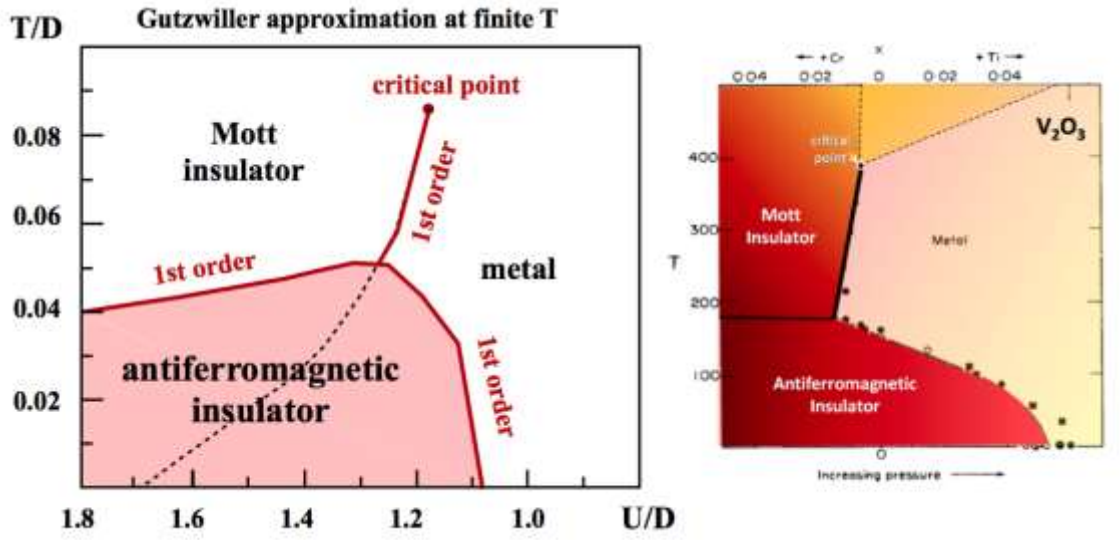


Figure 3 - Left panel: Phase diagram of a two-band model for V2O3 obtained by the Gutzwiller approximation. All transitions are first order. For comparison in the right panel we show the actual phase diagram of V2O3.

In the next figure we show the energy at zero temperature as function of the population imbalance **m** between the two orbitals. The ground state is the antiferromagnetic insulator (AFI) where the electrons occupy mostly the lowest

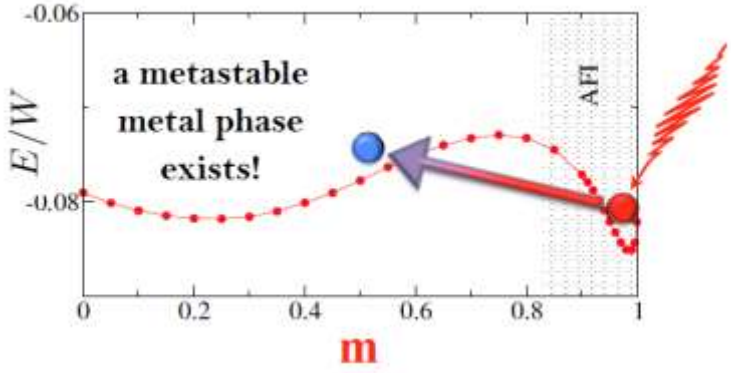


Figure 4 - Energy as function of the orbital polarization **m**. We note the absolute minimum at **m ≈ 1**, which corresponds to the stable magnetic Mott insulator (AFI), and the relative minimum at **m ≈ 0.3**, which corresponds to a metastable metal. Also sketched is the hypothetical photo-excitation that may drive the system into the metastable phase.

energy orbital, i.e. **m ≈ 1**. However the energy has another relative minimum at intermediate values of **m**, which is metallic. If we induce cross-gap excitations that transfer electrons from the lowest orbital to the highest one, i.e. temporarily reduce the value of **m**, we can drive in system in the basin of attraction of the metastable metal.

By means of the time-dependent Gutzwiller approximation, we showed that a sudden quench **m ≈ 1 → m_i < 0.8** can indeed trap the system into the metastable metal collapsing the gap down, as shown in the figure.

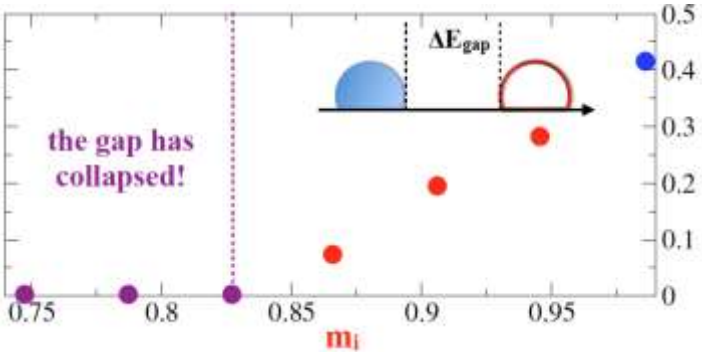


Figure 5 - Long-time value of the gap between the valence and conduction bands (each referring to a different orbital) as function of the initial non-equilibrium value of $\mathbf{m}_i$. We note that above a threshold the gap closes.

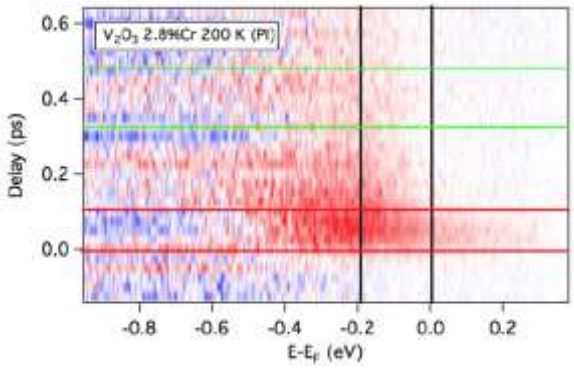


Figure 6 - Time-resolved photoemission spectrum of V_2O_3 after an intense ultra-short laser pulse, as function of the energy and the delay after the pulse. We observe the transient closing of the gap, indicated by the vertical black lines, that opens again on a picosecond scale, a very large time for electronic excitations.

We indeed observed this intriguing metallization in pump-probe femto-ARPES on V_2O_3, as shown in the figure. We believe that the physical phenomenon that we discovered has a more general validity than the simple model where we disclosed it, and raises a lot of interesting conceptual questions with practical consequences worth being addressed in the future. First of all, one should re-examine known narrow-gap Mott insulators to uncover how such physics can be realized, i.e. to find the observable that plays the role of **m** above and that can be varied experimentally. This information is crucial to evaluate the potentials of each material for applications. In addition one has to understand how typical phenomena that appears at first order transitions, like nucleation or wetting at interfaces, manifest themselves in such a novel context of metal-insulator transitions.

MSA3 Non-thermal ultrafast effects in superconducting copper oxides

All the time-resolved experiments carried out on copper oxides evidenced a dramatic difference between the simply heating of the system and the excitation through an ultrashort light pulse. While at the thermal equilibrium the largest number of excitations should be in the nodal region of the Brillouin zone (where the superconducting gap is zero), time-resolved techniques evidenced a very effective increase of the ANTINODAL excitations. This result suggests the possibility of using this non-thermal distribution as an additional knob to control the electronic properties of the material and, eventually, to define the most promising strategies

to optically switch the system from the normal to the superconducting phase and viceversa.These findings triggered an intense activity within the WP4 of the GO FAST project, to measure and model the effects of this non-thermal photo-excited distribution on the macroscopic electronic properties of different families of prototypical copper oxides. Among the different results, we briefly discuss here, as an example, the physical picture emerging from the time-resolved study [Cilento2014] of the pseudogap phase of copper oxides, which provides a very clear example of the novel conducting properties that emerge in non-equilibrium conditions.

The pseudogap state of copper oxides is defined by a $T^*(p)$ line in the doping-temperature (p-T) phase diagram that progressively vanish as the doping increases. The pseudogap is characterized by a Fermi surface that is gapped at the antinodes, even though the superconductivity is not observed. As far as the ultrafast dynamics is concerned, it is mandatory to understand the role of the antinodal (pseudo)-gap in the relaxation dynamics of the photoexcited population. To address this issue, we combined broadband pump-probe optical spectroscopy to time-resolved photoemission spectroscopy. We performed the experiments on Bi2212 and and $HgBa_2CuO_{4+\delta}$ (Hg1201) single crystals at different hole concentrations. Time-resolved photoemission unveiled the creation of a non-thermal electron distribution characterized by an excess of antinodal excitations. On the other hand, broadband pump-probe spectroscopy evidenced an anomalous decrease in the scattering rate of the charge carriers in a pseudogap-like region of the phase diagram. In other terms, when excited the system becomes more conducting than in the equilibrium condition. These findings suggest the following scenario:

- In the pseudogap region, delimited by a well-defined $T^*_{neq}(p)$ line, the non-thermal photoexcitation process triggers the evolution of antinodal excitations from gapped (localized) to delocalized quasiparticles characterized by a longer lifetime. As a consequence, a decrease of the scattering rate is observed as long as the non-thermal antinodal population is maintained.

The transient increase of the conductivity observed in the pseudogap state of copper oxides suggests that the $T^*(p)$ line delimits a region in which the antinodal states evolve into more metallic ones upon photoexcitation with the pump pulses. The generality of the results obtained called for a general model that accounted for the phase diagram unveiled by the non-equilibrium optical spectroscopy. Considering that the measured transient decrease in the carrier scattering rate was faster than the complete heating of the lattice, we focused on the 2D Hubbard Hamiltonian, i.e., the minimal model that neglects electron-phonon coupling and retains the genuine physics of correlations. To compute the temperature-dependent electronic self-energy in different positions of the Brillouin zone, we used the dynamical cluster approximation, a cluster extension of Dynamical Mean Field Theory (DMFT) that captures the **k**-space differentiation of the electronic properties between different **k**-space regions [Cilento2014]. In the first stage, the increase in energy related to the pump excitation was mimicked by selectively increasing the effective temperature of the nodal and antinodal self-energies. The results obtained through the modeling, suggest a strong dichotomy between the scattering rate of nodal and antinodal excitations. In contrast to nodal QPs, whose scattering rate increases with temperature, the scattering rate of antinodal excitations exhibits a completely different evolution, decreasing as the effective temperature rises. This striking

dichotomy of the nature of the elementary excitations in the **k**-space is the consequence of a momentum-space selective opening of a correlation-driven gap, which eventually evolves into the full Mott gap at p=0. When the hole doping is increased, the **k**-space differentiation of the nodal-antinodal fundamental excitations is washed out and a more conventional metallic behaviour is recovered. These calculations confirm an intrinsic U-driven momentum-space differentiation of the electronic properties of cuprates at finite hole concentrations and temperatures: the nature of the antinodal states is similar to that of a Mott insulator in the sense that the scattering rate of AN states decreases when the internal energy of the system is increased. These results explain the experimentally observe pseudogap-related photoinduced increase of conductivity when a non-thermal antinodal population is created [Cilento2014].

These results perfectly exemplify how to exploit the non-thermal distribution created by an ultrashort light pulse to manipulate the conductivity of copper oxides and transiently create artificial electronic properties that do not exist at equilibrium. These observations constitute the background from which various KERs (KER1,3,5,6,7) were developed. Besides the KERS, we also summarize the other most relevant scientific results that are strictly related to the study of the non-equilibrium physics of copper oxides:

- During WP4, we performed time-resolved photoemission spectroscopy with Vacuum UltraViolet (VUV) pulses on copper oxides. This experiment, performed at the beamline ARTEMIS at the Rutherford Laboratories (UK) allowed us to track, for the first time, the photoexcitation process in copper oxides within the entire Brillouin zone. The results evidenced a giant and unexpected increase of electrons at the antinodes and a long-lived modification of the oxygen bands at 1.5 eV binding energy.
- We performed high-temporal resolution (<10 fs) pump-probe spectroscopy on different families of copper oxides to directly measure, for the first time, the ultrafast coupling of the photo-excited charge carriers to magnetic bosons. [DalConte2015]
- We performed pump-probe optical spectroscopy on La_2CuO_4 and Bi2201 that evidenced the transient collapse of the charge-transfer gap in the underdoped region of the cuprate phase diagram. [Novelli2014]

KER1: METHOD of photodoping and its application to transistor-like devices

The possibility of photo-injecting a non-thermal distribution of excitations open interesting routes toward the optical control of the electronic phase in superconducting copper oxides. The possibility of using ultrashort light pulses to photodope the material has been recently demonstrated by time-resolved ARPES experiments.
The dynamics of the transient occupation of the electronic bands in copper oxides has been measured by time-resolved UV photoemission [Rameau2014]. The fourth harmonics (6 eV) of the output of an amplified Ti:sapphire oscillator has been employed to photo-emit electrons. A 40 fs pulse at 1.5 eV photon energy is used to excite the system. By changing the orientation of the sample and the delay t between the pump and probe pulses, the dynamics of the electronic bands in the k-space, i.e., E(**k**,t) is reconstructed. This technique has been applied to optimally doped $Bi_2Sr_2CaCu_2O_{8+\delta}$ (Bi2212) single crystals with T_c=96 K. Figure 1 (taken from Ref. [Rameau2014]) displays the relative variation of the photoemitted spectra at different delays. The Fermi energy is indicated by a dashed line. The data demonstrate a transient

depletion of the states at $E<E_F$ and a transient filling of the states at $E>E_F$. From these data we can draw two main conclusions:

- The effective mass of the charge carriers (holes) transiently decreases suggesting that the optical excitation directly modifies the electronic interactions that are responsible of the kinks in the bare band. This dynamics has the same timescale of the experimental temporal resolution (100 fs), thus pointing to a possible role of the magnetic excitations (antiferromagnetic fluctuations) that are expected to interact with the charge carriers on a very fast timescale (<20 fs).
- After the photoexcitation, the fermi energy progressively moves to smaller values of the momentum **k**. This behaviour is analogous to the effect of an increase of the chemical doping. These results suggest that, within 500 fs, the photoexcitation process can be considered as a transient photodoping that drives the physical properties of the system along a horizontal line in the phase diagram.

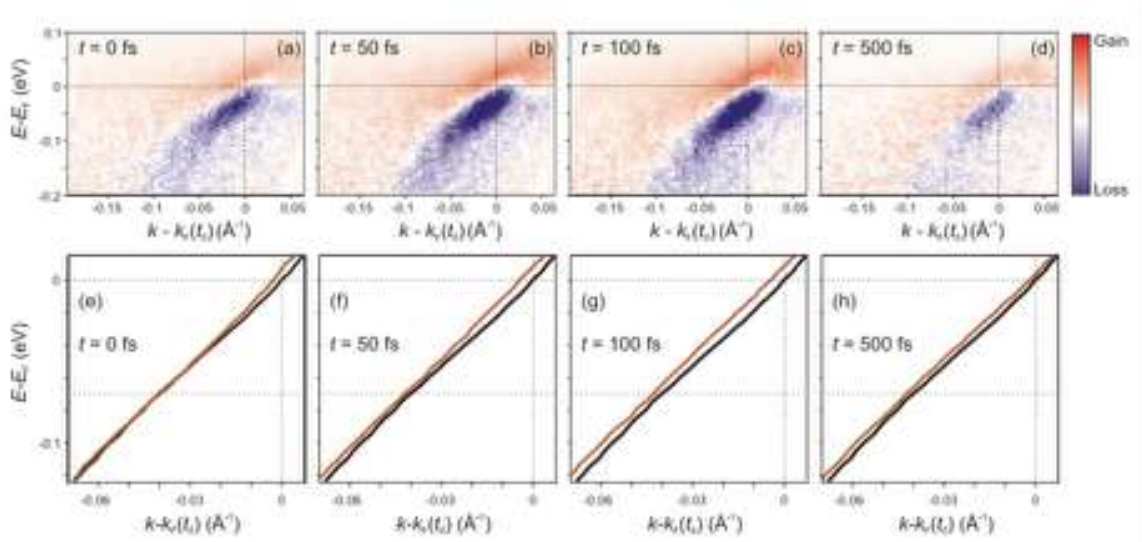


Figure 7 - (a)-(d) Laser-pump-induced photoemission intensity difference as a function of momentum and energy in a blue-white-red false color representation at indicated delay times. **(e)-(h)** show the respective dispersions $E(\mathbf{k})$ determined from Momentum-Distribution-Curve maxima in red. In black, the dispersion before optical excitation at t=0 fs is shown for comparison. Dotted lines through E_F, $\mathbf{k}_F$, and E-E_F=-70 meV are guides to the eye.

While the possibility of completely quenching the superconducting phase through an ultrashort light pulse is a well established experimental fact, the opposite process, i.e. the creation of a transient superconducting state is still a subject of intensive research. This would unlock the gate to the design of solid state switches (or transistor-like devices) that could change their conducting properties on the sub-picosecond timescale (i.e., 1-10 THz frequencies). The huge conductivity contrast between the normal state and the superconducting state, along with the relatively high critical current J_c of the superconducting state would make it possible a very high instantaneous current flow.

A promising strategy to pursue this objective, emerges from the femto-ARPES data. Furthermore, the electron-hole asymmetry in the cuprates also plays a fundamental role during the recovery dynamics. While the excitation process create electron-hole pairs, the following dynamics can be very different for the electrons and the holes. This gives rise to a shift of the chemical potential, as observed by time-resolved photoemission, that can simulate a transient increase of doping that is recovered within <1ps. These observations open very intriguing scenarios in which the hole doping *p* could be transiently increased in order to enter the superconducting dome and trigger a transient superconducting state. This seems to constitute a promising scheme for a realistic ultrafast (1 THz bandwidth) normal-to-superconducting switch that would operate at low temperature. The optical excitation could be provided through a fiber tip in order to miniaturize the device size down to approximately 1 μm. A thickness of 100 nm of the superconducting film should guarantee a homogeneous excitation profile that should limit possible problems related to the transversal diffusion of the

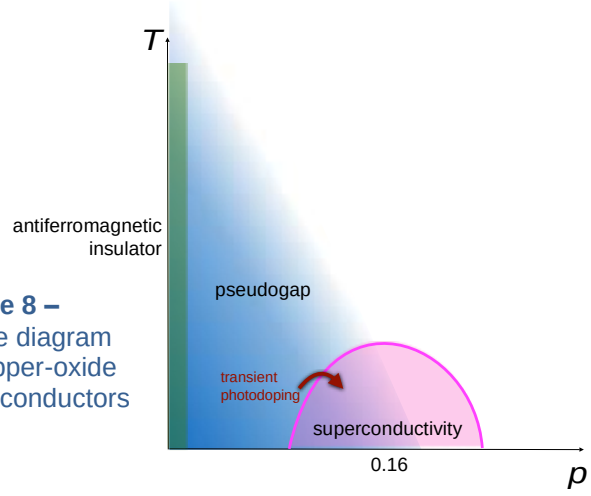


Figure 8 – Phase diagram of copper-oxide superconductors

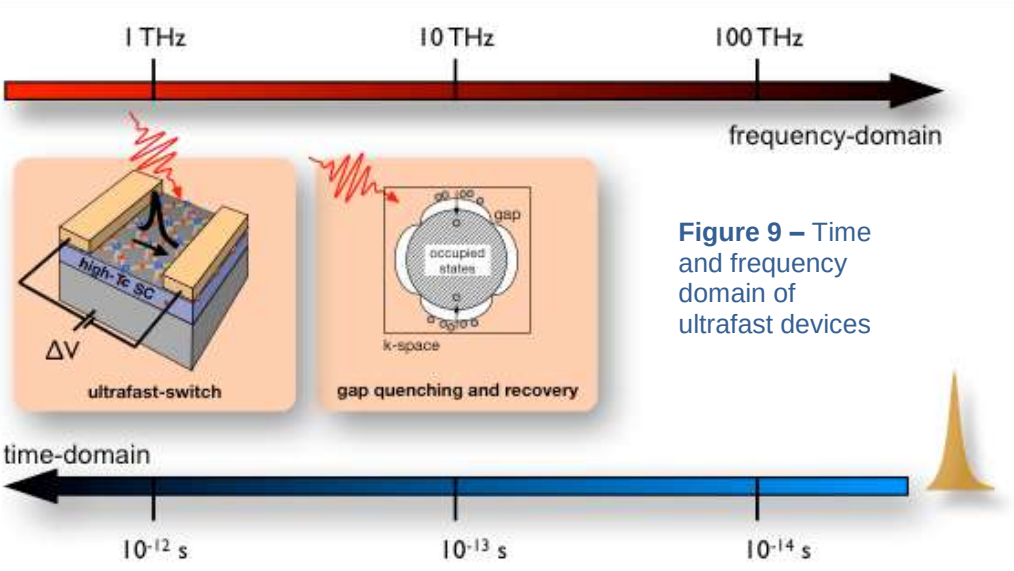


Figure 9 – Time and frequency domain of ultrafast devices

excitation. As far as the chemical composition of the copper oxides is concerned, $Bi_2Sr_2CaCu_2O_{8+\delta}$ seems the most simple system to start with, even though YBCO could have some advantages since it is already more used at the industrial level and YBCO thin films are commercially available. The doping and the operating temperature of the system should be tuned considering the shape of the superconducting dome, that is reproduced by the phenomenological formula: $T_c/T_{c,max}=1-82.6(p-0.16)^2$, where $T_{c,max}=96$ K for Bi2212. For example, considering that the contrast of the switch is expected to be larger in the underdoped region and at low temperature, we can fix $T_c=4$ K and we obtain an equilibrium hole doping of about $p=0.05$. On the other hand, it could result useful to operate at higher temperatures, even though the superconducting dome becomes progressively parallel to the p axis when approaching optimal doping. Considering the liquid nitrogen temperature, $T_c=77$ K, we obtain $p=0.11$.

[Rameau2014] J. D. Rameau et al. *Photoinduced changes in the cuprate electronic structure revealed by femtosecond time- and angle-resolved photoemission*. Phys. Rev. B 89, 115115 (2014)

KER3: CODE to implement the time dependent dynamical mean theory t-DMFT

One of the backbones for the theoretical investigation of non-equilibrium correlated materials has been the development of a code implementing the time-dependent dynamical mean-field theory (t-DMFT) both for simple models (Hubbard model) and for realistic descriptions of correlated materials.
From a formal point of view, t-DMFT does not require conceptual extensions with respect to equilibrium, and it amounts to solve iteratively an impurity model subject to a self-consistency condition. However, both aspects become much less obvious out of equilibrium. Our development of a t-DMFT code has worked in both directions using a modular approach.

We have developed a completely general Fortran driver which solves the self-consistency equations (essentially the Baym-Kadanoff-Keldysh equations with a local self-energy) in an effective and optimized way. This part of the code has been designed in order to be completely general, in order to study normal metallic phases, superconductivity, magnetic ordering, it is interfaced with the popular software Wannier90, which implies that it can be used with most Density-Functional Theory packages and codes, and it introduces non standard features, unavailable in other implementations of t-DMFT, like inhomogeneous states (by means of real-space DMFT algorithms). The modular and flexible structure of the code allows to include other features, like electron-phonon interaction including a full phonon dynamics, multiorbital and cluster structures.

This part of the code works like a black box which can be interfaced with different “impurity solvers”, which solve the impurity model out-of-equilibrium. About this part, it has become clear that none of the available solvers can be considered more effective than others irrespective of the physical problem, regime of temperature and other model-specific aspects. It is therefore crucial to implement different solvers to be used in different regimes (and to be benchmarked one against the other in the regimes where they simultaneously work).

We have successfully implemented the simple, yet approximate, Iterated Perturbation Theory IPT, where particular effort has been devoted to the superconducting state, which has not been included in previous implementations. The full IPT code is completely operational and it is

currently applied to a range of problems. The code is close to a level where it can be distributed and provide a simple solution to most strongly correlated models out of equilibrium.

The Continuous-Time Quantum Monte Carlo has been implemented in the hybridization expansion. The code is operational and “numerically exact”, but it can not be used for times longer than 100 fs because of numerical noise. We are currently working on minimizing the influence of such noise on the actual observables. Finally, we are developing a new kind of solver based on exact diagonalization, but this tool is still in the development stage.

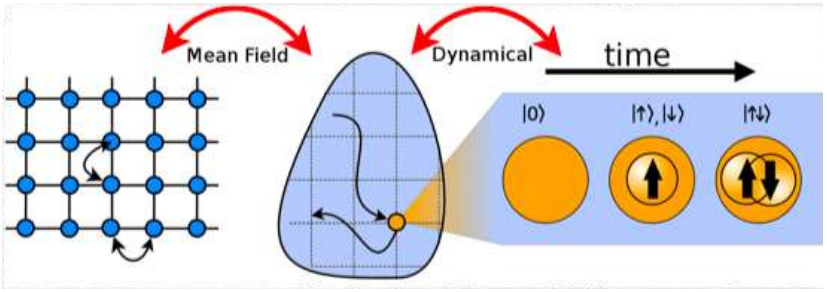


Figure 10 - Schematic view of the t-DMFT loop implemented in our code.

KER5: CODE for the analysis of pump-probe THz spectroscopy experiments

As a fall-out of the main scientific tasks of the GO-FAST project, the Exploitation Board (EB) individuated some modelling tools that could be of relevance for technology-oriented applications. As far as the THz business of MenloSystems is concerned, the THz line (optical antennas and detectors and time-domain THz kit) is supported by the TeraLyzer software that allows extracting the optical constants from time-domain THz measurements. In this perspective, some of the GO-FAST partners tackled the problem of reconstructing the change of the THz optical conductivity, after the excitation with an optical ultrashort light pulse. In this configuration, called optical pump-THz probe, the large mismatch between the penetration depths of the optical and THz pulses makes the dynamics of the pump-probe experiment intrinsically inhomogeneous. As shown in the figure, the THz electric field reconstructed from

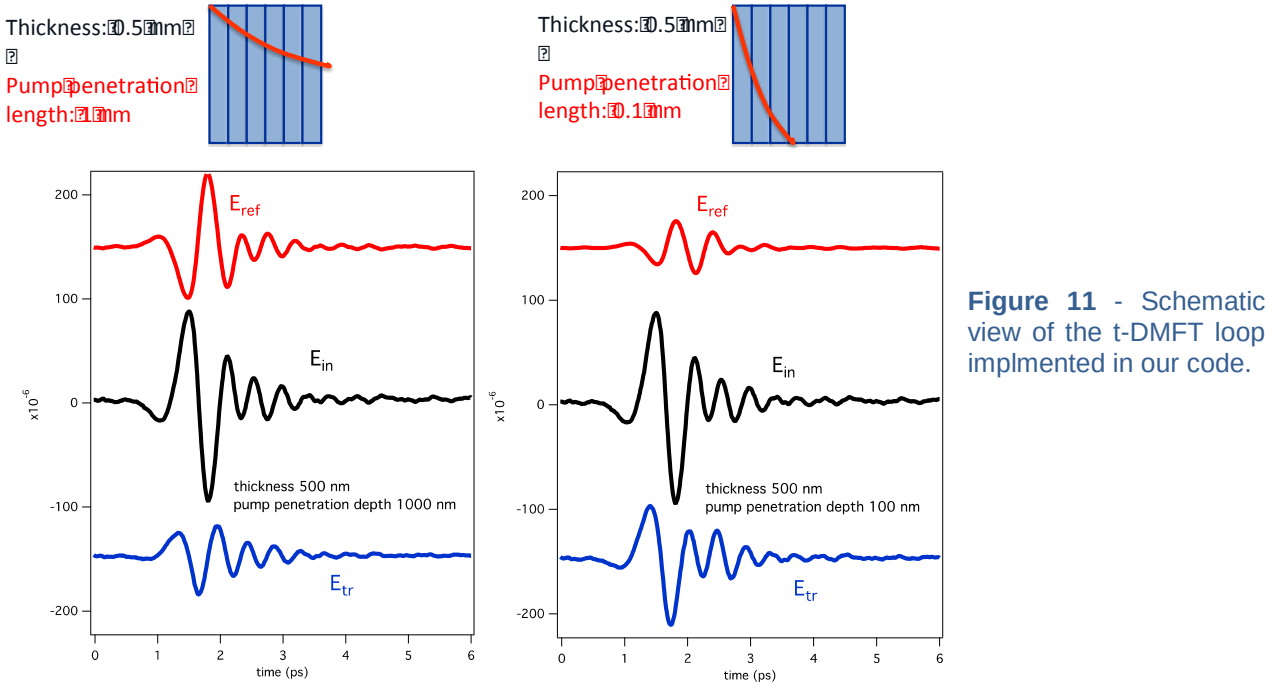


Figure 11 - Schematic view of the t-DMFT loop implmented in our code.

the electro-optical sampling strongly depends on the profile of the excitation pulse. Therefore, the deconvolution between the measured signal and the spatial profile of the pump pulse is mandatory to extract the dynamics of the optical constants which can be successively used for extracting the physical informations about the process under study. Considering that the optical pump-THz probe configuration is raising increasing commercial interest, the EB suggested the possibility of developing a GO-FAST tool for the analysis of pump probe THz experiments, which could be eventually considered as tool of the TeraLyzer software.

KER6: CODE for the dynamics of the order parameter in a symmetry-broken phase

In order to describe the spatial propagation of the impulsive perturbation of the superconducting order parameter, we used the Ginzburg-Landau functionals. The motion equation that is obtained is a wave equation with a damping term. This partial differential equation can be solved through the finite-elements approach, taking into account the realistic geometry of the system. In the limit of large damping, that corresponds to the thermodynamic limit, the order parameter relaxes back to equilibrium without oscillating and the dynamics reduces to a diffusion process. As a first step we modelled the dynamics of the order parameter in a thin film of finite thickness and we studied the role of the laser penetration depth in destroying the superconducting phase. In the figure we report the average value of the order parameter probed by the optical pulse, as a function of the intensity (arb. units) and penetration depth of the pump pulse. In the homogeneous limit (i.e., the pump penetration length is significantly larger than the thickness), the average value of the order parameter is linear with the pump fluence until the threshold corresponding to the complete destruction of the superconducting phase is reached. In the opposite case (i.e., the pump penetration length is significantly smaller than the thickness) we observe a non linear regime, in which the phase transition has already happened in a small superficial volume of the system.

This model has been used to analyze pump-probe data on a bulk high-temperature superconductor (Y-Bi2212) and precisely estimate the critical fluence necessary to optically quench the superconducting phase in the first layer of the system. The tool developed during this activity is very versatile and can be extended to any kind of symmetry-broken phase that is locally and impulsively perturbed.

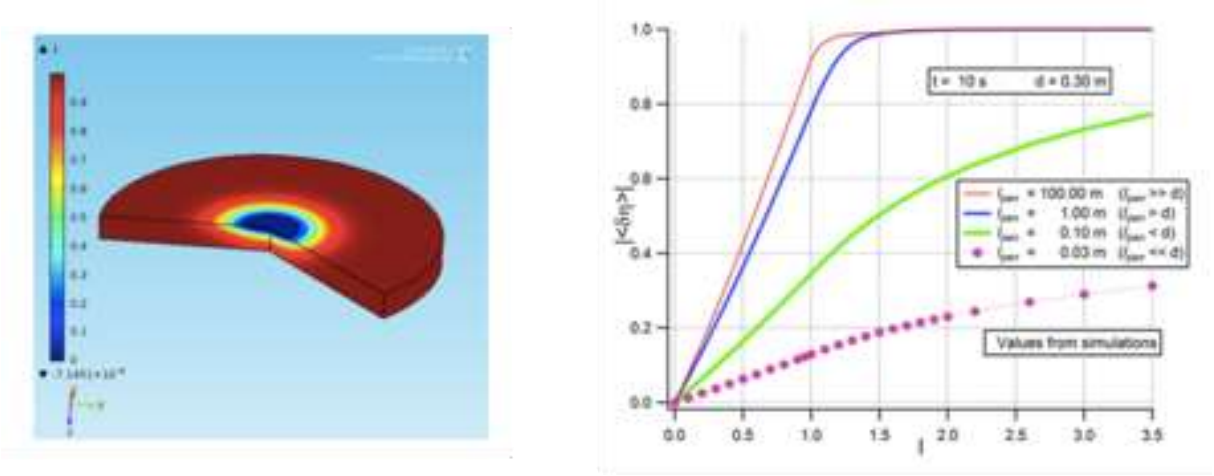
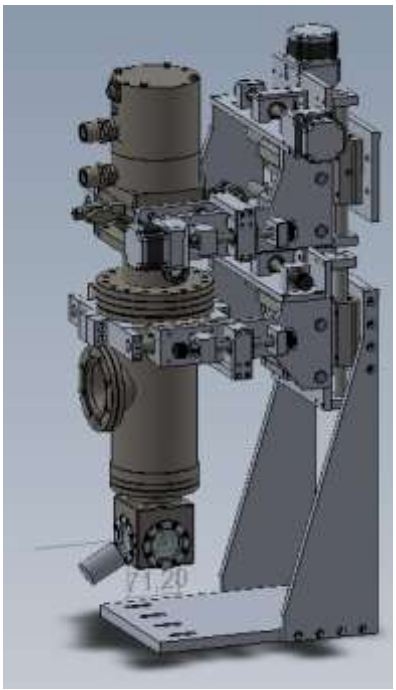


Figure 12 - Left panel: colour plot of the dynamics of the superconducting order parameter in a film of finite thickness. Right panel: average relative quench of the order parameter as a function of the pump intensity for different pump penetration lengths.

The EB suggested the possibility of developing a GO-FAST tool, based on commercially-available finite-elements software, that allow the solution of GL equations in symmetry-broken phases in a simple and versatile fashion. This software could be further extended to study supelattices constituted by alternate layers of materials with different order parameters, which constitute a promising route towards the manipulation of the physical properties of solid-state systems.

KER7: DESIGN of 3D cryostat managing system



During the project we tackled the problem of developing a 3-degrees-of-freedom-mechanical handling system (manipulator) to control and move the closed-cycle cryostat employed for the low-temperature optical measurements. Since the cryostat (ARScryo) is constituted by two mechanically-decoupled parts that should be moved in a synchronized way, we developed a 6-motors synchronized manipulator that avoids transmitting the vibrations of the compressor to the sample, while leaving the freedom of moving the samples. The manipulator has been designed and assembled in the labs of the UNICATT partner. The manipulator is controlled via a software written in the Labview (National Instruments) code. The design of this manipulator raised the interest of Italian distributor of ARSCryo, that is available to jointly develop a commercial prototype that could be offered to the customers interested in this solution. In view of the possible commercialization, the consortium is studying the most suitable form of design protection.

[Cilento2014] F. Cilento et al. *Photo-enhanced antinodal conductivity in the pseudogap state of high-Tc cuprates*. Nat. Commun. 5:4353 doi:10.1038/ncomms5353 (2014).

[Rameau2014] J. D. Rameau et al. *Photoinduced changes in the cuprate electronic structure revealed by femtosecond time- and angle-resolved photoemission*. Phys. Rev. B 89, 115115 (201

4.1.4. Description of the potential impact (including the socio-economic impact and the wider societal implications of the project so far) and the main dissemination activities and the exploitation of results

1.4.1.1 Socio-economic impact

The aforementioned results, which have been obtained during the three years of the project, point towards several research directions worth to be further pursued in the future. In particular, the non-thermal photo-induced behaviour observed in vanadium- and copper-oxides superconductors foreshadows quite remarkable phenomena; a great challenge that we do intend to take up. In addition, the preliminary and so far feeble evidence that one can optically nucleate droplets of a metastable metal phase within a Mott insulator discloses interesting perspectives to exploit the first order nature of known Mott transitions, which are hitherto unexplored.

The new concepts and modelling tools introduced by the GO FAST project and related to the non-equilibrium properties of correlated materials, can impact on the next-generation of solid-state devices, such as ultrafast memories and switches and THz devices, that are emerging as fundamental tools in the field of diagnostics and imaging. Even though the state-of-the-art technology is still based on “conventional” semiconductor devices, a huge effort is currently ongoing to investigate the capabilities of novel materials that could replace current technology. In this perspective, the knowledge developed by the GO FAST project in the field of non-equilibrium correlated materials is strategic in view of establishing funding concepts for the potentially immense market of next-generation ultrafast solid-state devices. The possibility of modelling the ultrafast properties of correlated oxides, demonstrated by GO FAST on the prototypical vanadates and cuprates, reinforces the leading role of the European science in the worldwide race towards the development of novel materials whose functionalities can be artificially manipulated with unprecedented speed.

1.4.1.2 Dissemination

Several actions have been undertaken during the whole course of the project to promote the project’s results both within the consortium, and in the European industrial and universal scientific communities, in order to increase public awareness of the project. The project could rely on a website, which has been constantly updated during the whole course of the project lifetime, and will be kept alive for other 5 years and will continue updating the external audience on news related to the project’s partners and on their research works.

In order to spread information on the project, a periodical newsletter have been sent out to promote the results achieved so far. External users could subscribe to the newsletter service through the form available in the homepage of the project website. Finally, the Project Office acted as interface with the external users through the email info@gofastproject.eu.

Moreover, the project has been widely disseminated mostly during internationals events such as conferences, workshops, and through a significant number of publications and articles. The scientific results achieved within the project have been make known to the scientific community

through articles that have been published in the most prestigious international journals. Moreover, in occasion of the project meetings or when articles were published in particularly prestigious journals, dissemination initiatives towards the non-scientific community have been undertaken.

The success of the project is demonstrated by the important number of publications in high impact factor journals, such as: 49 publications of which 4 in Nature journals, 4 in Physical Review Letters, 2 in Scientific Reports, 15 in Physical Review B, and an invited review in Advanced in Physics, to appear in 2015. The complete list of articles is included in the Annex I to this document.

In addition, all members of the consortium have presented their main achievements within GO FAST in important international conferences. During the whole course of the project, the partners made more than 70 dissemination activities, of which most are oral presentations to a scientific event, followed by poster presentations.

On October 2013 SISSA organized an international conference held at the International Centre for Theoretical Physics in Trieste that was very successful, with more than 100 participants. All talks of the conference were recorded and made available on-line. The conferences program is available in the II periodic report of the GO FAST project.

Then, in collaboration with the FEMTOSPIN project, a joint summer school was organized at Nijmegen, in the Netherlands. The Summer School Multiscale Dynamics in Condensed Matter - Non-equilibrium spectroscopy of correlated materials and superconductors, was organized by RU in and took place in August 2014. And five more workshops and a seminar have been organized during the whole course of the project lifetime, as shown in the table hereunder.

Finally, the Editor of Advanced in Physics recently contacted us to write a review paper, which is going to appear this year with the title “Ultrafast optical spectroscopy of strongly-correlated materials: a non-equilibrium approach”.

Finally, an important part of the dissemination undertaken by the GO FAST consortium, was aimed at interfacing with other running research projects at EU and national level to achieve effective interactions with other current project at the EU level. The projects potentially interested in GO FAST were already identified during the proposal preparation. In particular, a strong interaction with the projects CRONOS and FEMTOSPIN of the 7th Framework Programme have been established. The first activity planned was the organization of the Cluster Workshop “Theory meets Industry”, which was held the 27th-28th November 2014, in Dublin, and was hosted by the coordinator of the CRONOS project, the Trinity College of Dublin. Then, as a result of a deep activity done by the three consortia to identify the key exploitable results among the big mole of knowledge generated by the projects themselves, the Cluster Exploitation Workshop of three femtodynamics projects was held on 10th and 11th of March 2015 in Brussels, with the aim of reviewing these projects in view of the industrial exploitation of the newly developed modelling and simulation capabilities.

The review was done against the FP7 contract issued by a programme called “Industrial Technologies". However, as pointed out by Anne de Baas in her introductory remarks, as F7 is transitioning to H2020 there is an increasing emphasis by the European Commission on the impact of modelling software and know-how on the global competitiveness of the European industry. This is in accordance with the Roadmap for Materials Modelling as formulated by the European Materials Modelling Council (EMMC). The reviews were thus requested to focus on industrial exploitation potential of the three projects, that demonstrated a high level of scientific achievements and significant progress in the development of new software, thus reinforcing

the scientific leadership of European research groups in the field of computational materials science. While the industrial exploitation of these new software capabilities has started, the full potential of these innovative software achievements remains to be developed.

1.4.1.3 Exploitation

In view of the possible exploitation of some of GO FAST outcomes, we report the list of the KERS but now discussing details of the possible IPR protection and the form that the exploitation of these results can take (direct industrial use; patenting, technology transfer, license agreement, publication, standards). The KERs, which have been described in detail earlier, have been organized in:
GROUP 1: CODE related issues (KER 3,5,6)
GROUP 2: THEORY/METHODS related issues (KER 1,2,4)
GROUP 3: Product model related issues (KER 7)

GROUP 1: CODES

KER3: CODE to implement the time dependent dynamical mean theory t-DMFT

This KER concerns the implementation of time-dependent DMFT codes flexible enough to be implemented in popular platforms. This action is still underway, although several important progresses have been achieved and applied to model experimental data that have been included in relevant publications.

Innovativeness introduced compared to already existing Products/Services	Specific key scientific results have been implemented in the code – for example superconductivity
Unique Selling Point (competitive advantages)	The code is currently freely distributed, through a GPL licence, from the code web page. This key exploitable result is not a separate piece of software, but a whole set of new additions to an already existing code, that was used as base for the project. The code (with all these additions), is released with the protection of the General Public License. This means that the code is freely available, and users are free to copy, inspect, modify, and redistribute it. This means that anyone (researchers, industry) is free to exploit the outcome of the project. This is valid for the full code, and in particular for the new additions that constitute this KER. Those cannot be found in any code, and therefore can be considered to be innovative. There do, however, exist competing codes that could easily incorporate the new additions, especially since they are thoroughly described in the corresponding research papers. A business may grow around a piece of free software, and numerous examples exist. It would provide services around it, such as support, training, etc. However, there are no competing advantages that we can think of.
Product/Service Market Size	The code is currently used by a few tens of people. The KER itself, however, is still only used by a core set of developers. The community interested in QOCT for materials science is very difficult to estimate.
Market Trends/Public Acceptance	Possible upheave due to (albeit currently unlikely) switch of use of technology for the electronics in general.
Product/Service Positioning	The target users are: Academic research community, industry with R&D units dedicated to modelling with first principles techniques.
Legal or normative or ethical requirements (need for authorisations, compliance to standards, norms, etc.)	None that we know of.
Competitors	Various academic-only users.

Prospects/Customers	Academia
Cost of Implementation (before Exploitation)	The key scientific results have already been implemented. In order to achieve exploitation, however, probably new actions should be taken, such as increasing the documentation, the user-friendliness, the separation of the KER from the full code, licensing, etc. This should be handled professionally It is of course the key to successful exploitation. The profile must be combined: software engineering + scientist (physics, chemistry). Around €40000/year.
Foreseen Product/Service Price	Unknown
Adequateness of Consortium Staff	The members of the Consortium can safely develop the scientific part. The possibility of exploitation (commercial or otherwise), however, would require special help on this area
Status of IPR: Background (type and partner owner)	The code is copyrighted through the GPL.
Status of IPR: Foreground (type and partner owner)	The code is copyrighted through the GPL.
Status of IPR: Exploitation Forms (type and partner owner) e.g. direct industrial use, patenting, technology transfer, license agreement, publications, standards, etc.	The code is copyrighted through the GPL.
Which partner contributes to what (main contributions in terms of know how, patents, etc.)	SISSA
Partner/s involved expectations	Partners expect the tool to be freely used for their own continuation of the academic work, and also among other scientists.
Sources of financing foreseen after the end of the project (venture capital, loans, other grants, etc.)	None Thinking about applying for another EU project

KER5: CODE for the analysis of pump-probe THz spectroscopy experiments

During the project we developed a new tool for the analysis of pump-probe THz spectroscopy experiments. The tool is based on the transfer matrix and allows the user to extract the variation of the optical conductivity, dielectric function and refraction index of the sample investigated, accounting for the penetration depth of the optical pump pulse.

Innovativeness introduced compared to already existing Products/Services	No such a tool is commercially available. Specific key scientific results have been implemented in the code – for example the demonstration of the possibility of retrieving the dynamics of the optical functions in strongly in-homogeneously excited system. These results are related to the pump-THz probe measurements carried out in WP1 and WP4.
Unique Selling Point (competitive advantages)	The code is currently freely distributed, through a GPL licence, from the code web page. This key exploitable result is not a separate piece of software, but a whole set of new additions to an already existing code, that was used as base for the project. At the moment, the code (with all these additions) is released with the protection of the General Public License. This means that the code is freely available, and users are free to copy, inspect, modify, and redistribute it. This means that anyone (researchers, industry) is free to exploit the outcome of the project.
Product/Service Market Size	At the moment the interest is limited to research groups, however the interest could rapidly spread once applications to technologically relevant materials are demonstrated.

	The code is currently used by a few tens of people. The KER itself, however, is still only used by a core set of developers. The community interested in QOCT for materials science is very difficult to estimate. This is valid for the full code, and in particular for the new additions that constitute this KER. Those cannot be found in any code, and therefore can be considered to be innovative. The present code can be easily implemented as a tool of the most used data analysis softwares, such as Matlab, Igor Pro Wavemetrics and the Teralyzer software by Litera, that is commercialized by MenloSystems for THz analysis. On the other hand, considering that the methods employed are thoroughly described in the literature, similar software could be reproduced by other research groups, making a business based on that rather difficult. Other kind of business may grow around a piece of free software, and numerous examples exist. It would provide services around it, such as support, training, etc. However, there are no competing advantages that we can think of.
Market Trends/Public Acceptance	Possible upheave due to (albeit currently unlikely) switch of use of technology for the electronics in general.
Product/Service Positioning	The target users are: Academic research community, industry with R&D units dedicated to modelling with first principles techniques.
Legal or normative or ethical requirements (need for authorisations, compliance to standards, norms, etc.)	None that we know of.
Competitors	Various academic-only users.
Prospects/Customers	Academia
Cost of Implementation (before Exploitation)	The key scientific results have already been implemented. In order to achieve exploitation, however, probably new actions should be taken, such as increasing the documentation, the user-friendliness, the separation of the KER from the full code, licensing, etc. This should be handled professionally. It is of course the key to successful exploitation. The profile must be combined: software engineering + scientist (physics, chemistry). Around €40000/year.
Time to market	N/A
Foreseen Product/Service Price	Unknown
Adequateness of Consortium Staff	The members of the Consortium can safely develop the scientific part. The possibility of exploitation (commercial or otherwise), however, would require special help on this area
External Experts/Partners to be involved	MenloSystems, Litera
Status of IPR: Background (type and partner owner)	The code is copyrighted through the GPL.
Status of IPR: Foreground (type and partner owner)	The code is copyrighted through the GPL.
Status of IPR: Exploitation Forms (type and partner owner) e.g. direct industrial use, patenting, technology transfer, license agreement, publications, standards, etc.	The code is copyrighted through the GPL.
Which partner contributes to what (main contributions in terms of know how, patents, etc.)	UNICATT mainly developed the tool
Partner/s involved expectations	Partners expect the tool to be freely used for their own continuation of the academic work, and also among other scientists.
Sources of financing foreseen after the end of the project (venture capital, loans, other grants, etc.)	None Thinking about applying for another EU project

KER6: CODE for the dynamics of order parameters in symmetry-broken phases

During the project we developed a tool for reproducing the spatial and temporal dynamics of the order parameter in a broken-symmetry phase driven out-of-equilibrium. The tool is based on the numerical solution obtained by the finite-element method of the equations of motion within a time-dependent Ginzburg-Landau (GL) functional. The tool developed can model the propagation of a local perturbation within a nanostructured system, and compute the propagation of a local perturbation. However, this tool can be easily extended to any system characterized by a broken-symmetry phase, such as charge-density wave systems and metal-to-insulator transitions. These systems are relevant for technological applications since they can be potentially employed for ultrafast switching applications.

Innovativeness introduced compared to already existing Products/Services	No such a tool is commercially available. Specific key scientific results have been implemented during the project. Within the WP2 (Scaling to the nanosize) we have studied the problem in simple cases in which analytical solutions can be calculated. These results have been used as a benchmark for numerical solutions of the GL motion equation obtained by finite-elements softwares, such as COMSOL Multiphysics. The software is based on standard concepts in thermodynamics. Nonetheless, during the test many problems regarding the stability and reliability of the solutions have been tackled. As a whole, a massive know-how has been developed within GO FAST.
Unique Selling Point (competitive advantages)	These GO FAST activities led to self-standing software that allows calculating the spatio-temporal dynamics of an impulsive perturbation. Even though the solution of GL equation can be implemented starting form any finite-element software, the most promising route is to develop a protectable tool that is based on commercial finite-element software. In this perspective the new capabilities of the COMSOL Server and COMSOL Application Builders are the most promising to guarantee a widespread use of the software. The code is currently distributed to the GO FAST partners for research objectives. However, after suitable protection, it could be commercialized as a self-standing tool.
Product/Service Market Size	In the first step, the software could be of interest for academic application, ranging from the calculation of the spatio-temporal trajectories in broken-symmetry states to the design of superlattices, waveguides and cavities for perturbations that propagate following the wave equation. The approach used is completely general and enables to model any kind of broken-symmetry state. In a near future (3 years), this tool could be extended to simulate the propagation of a wavefront in a first-order phase transition process. This could be of great relevance to study the dynamics of the switching process in solid state non-volatile memories and other nanometric devices. In this case, the market could significantly expand, since the possible interest would involve all the technology-oriented companies with R&D activities that need to simulate a local switching of materials for solid-state memories.
Market Trends/Public Acceptance	Possible positive trend once the electronics companies get interested in it.
Product/Service Positioning	The target users are: Academic research community, industry with R&D units dedicated to modelling with first principles techniques.
Legal or normative or ethical requirements (need for authorisations, compliance to standards, norms, etc.)	None that we know of.
Competitors	Various academic-only users. Finite-elements software-houses.
Prospects/Customers	Academia and electronics companies with R&D activities.
Cost of Implementation (before Exploitation)	The key scientific results have already been implemented.

	In order to achieve exploitation, however, new actions should be taken to produce a suitable documentation and to combine all the results in a single software that could run using a solver that is easily available on the market and possibly accessible to all non–experts customers. In this perspective, the use of the COMSOL Server and COMSOL Application Builders are the most promising to guarantee a widespread use of the software. This step has to be handled professionally. It is of course the key to successful exploitation. The profile must be combined: software engineering + scientist (physics, chemistry). Around €40000/year.
Time to market	3 years
Foreseen Product/Service Price	Self-standing tool for simulation of the dynamics of local phase transition and for the calculation of the properties of engineered heterostructures.
Adequateness of Consortium Staff	The scientific concepts have been already developed within the Consortium. The possibility of exploitation however, would require an additional professional support.
External Experts/Partners to be involved	Comsol Multiphysics
Status of IPR: Background (type and partner owner)	none
Status of IPR: Foreground (type and partner owner)	The code is for internal use.
Status of IPR: Exploitation Forms (type and partner owner) e.g. direct industrial use, patenting, technology transfer, license agreement, publications, standards, etc.	The code can be either copyrighted through the GPL or further protected for commercial use.
Which partner contributes to what (main contributions in terms of know how, patents, etc.)	UNICATT mainly developed the tool
Partner/s involved expectations	Partners expect the tool to be freely used for their own continuation of the academic work, and also among other scientists.
Sources of financing foreseen after the end of the project (venture capital, loans, other grants, etc.)	None Thinking about applying for another EU project

GROUP 2: THEORY and MODELS

KER 1: METHOD of photodoping and its application to transistor-like devices

As aforementioned, this KER concerns the possibility of exploiting the non-thermal self-doping observed in photo-excited cuprates for transistor-like devices.

Innovativeness introduced compared to already existing Products/Services	A method for Photodoping and its application to Transistor like devices has been submitted as a record of invention to the Brookhaven Laboratories. Such a method has previously not been developed and it offers (a) a new insight of possibilities into electronics involved in both computation and telecommunication; (b) fast switching in power applications (as opposed to information applications per se) that can handle large amounts of electrical current without damage
Unique Selling Point (competitive advantages)	(a) Increasing the rate at which transistors or equivalent three terminal devices may be switched between conducting (on) and non- conducting (off) states, thereby blocking or allowing the flow of current, respectively, in a circuit. Additionally, one may wish to integrate such devices directly into an optoelectronic architecture that forgoes metallic interconnects e.g. at the gate electrode, to some degree; (b) switching on-off very rapidly and handle large amounts of electrical current without damage at the same time

Product/Service Market Size	The market will strongly depend on the conditions of operation of the device. The potential future product might be fitted in a small fraction of the semiconductor market, which is 1k billion EUR.
Market Trends/Public Acceptance	No market tests available without product, market studies (or better overviews) hint a possible high acceptance of smaller, faster, reliable electronics.
Product/Service Positioning	No final product yet, TRL 1-2
Competitors	Research groups in US and EU only currently
Prospects/Customers	Electronics, computation, power supply, telecommunication, shares are difficult to predict due to early stage developments
Cost of Implementation (before Exploitation)	Approximation: 2 sequential EU projects involving at every step more industrial partners to commercialize the technology to the level TRL at least 5-6, approximately 10 million EUR. Then another 1-5 years of industrial testing, costs undeterminable at this point.
Time to market	At least 10 years
Foreseen Product/Service Price	At least comparable to current electronic devices; otherwise would not be competitive. However it is difficult to predict at this early stage
Adequateness of Consortium Staff	Adequate, but involve industry to a more relevant degree and higher responsibility level
External Experts/Partners to be involved	Think about relevant SMEs and MNEs to be included into the partnership
Status of IPR: Background (type and partner owner)	No patented IPR
Status of IPR: Foreground (type and partner owner)	No patented IPR
Status of IPR: Exploitation Forms (type and partner owner) e.g. direct industrial use, patenting, technology transfer, license agreement, publications, standards, etc.	Publications taking place. At TRL 1 difficult to establish with certainty a possible exploitation mode, in parallel with the semiconductor industry types of collaboration would likely be license agreements, spin out creation and standards later on.
Which partner contributes to what (main contributions in terms of know how, patents, etc.)	Main partners in this KER are UDE and SISSA.
Partner/s involved expectations	The partners expect the methods to develop to the level where they would be applicable at the industrial level, however, they would gradually decrease their level of collaboration and would leave the industrial partners to take charge.
Sources of financing foreseen after the end of the project (venture capital, loans, other grants, etc.)	EU projects. In later stages direct financing of the project collaborations by suitable industrial partners.

KER2: METHOD to study out-of-equilibrium models

This KER concerns a new variational method developed by GO FAST that allows to simulate the time-evolution of lattice models for correlated electron systems. The method is extremely simple and flexible as well as easy to implement.

Innovativeness introduced compared to already existing Products/Services	A result has been proved that allows relatively easily computing the non-equilibrium time-evolution of a Gutzwiller variational wave function
Unique Selling Point (competitive advantages)	The method has been presented in detail in an article appeared on a book, and it is freely available on the arXiv, http://arxiv.org/abs/1204.2175. In such a way people can become aware of the method, which can thus spread among the community.
Product/Service Market Size	It is difficult to estimate the market size. We expect that, if in the future we will be able to implement t-GA in the time-dependent DFT (TDDFT), the market size might become sizeable.
Market Trends/Public Acceptance	Since the method addresses strongly correlated materials, the market trends depend on the technological interest in such materials.
Product/Service Positioning	The target users are: Academic research community, industry with R&D units dedicated to modelling with first principles techniques.

Legal or normative or ethical requirements (need for authorisations, compliance to standards, norms, etc.)	None we are aware of.
Competitors	Other research groups
Prospects/Customers	Academia
Cost of Implementation (before Exploitation)	The method has already been implemented. The numerical code that implements it is relatively simple. What would be more involved is to combine the method with TDDFT. This task would likely require two Post Doc positions, roughly €40000/year.
Time to market	**N/A**
Foreseen Product/Service Price	Unknown
Adequateness of Consortium Staff	The members of the Consortium can safely accomplish the scientific task. The possibility of exploitation (commercial or otherwise), however, would require special help on this area
External Experts/Partners to be involved	None
Status of IPR: Background (type and partner owner)	Should the code be done, it would be copyrighted through the GPL.
Status of IPR: Foreground (type and partner owner)	Should the code be done, it would be copyrighted through the GPL.
Status of IPR: Exploitation Forms (type and partner owner) e.g. direct industrial use, patenting, technology transfer, license agreement, publications, standards, etc.	Should the code be done, it would be copyrighted through the GPL.
Which partner contributes to what (main contributions in terms of know how, patents, etc.)	SISSA
Partner/s involved expectations	Partners expect the tool to be freely used for their own continuation of the academic work, and also among other scientists.
Sources of financing foreseen after the end of the project (venture capital, loans, other grants, etc.)	None Thinking about applying for another EU project

KER4: THEORY on the reasons why the Mott gap collapses for several ps after an ultra short laser pulse

This is a KER that consists of a theoretical concept developed by the Consortium that we believe will have important practical consequences.

Innovativeness introduced compared to already existing Products/Services	While we are accustomed to semiconductors, where a metallic behaviour is only obtained by hole or electron doping, the possibility of coexistence between a stable insulator and a metastable metal is a new concept, whose consequences are still unknown and worth investigating.
Unique Selling Point (competitive advantages)	This concept has been emphasized in an article recently published in Physical Review B. This choice was taken because we think it is important to spread such an idea in the scientific community.
Product/Service Market Size	Presently the market size cannot be quantified, since it will depend on the new physical phenomena that the above coexistence could lead to.
Market Trends/Public Acceptance	There is currently a relatively intense activity on Motttronics, i.e. on electronics made with Mott insulators, which could be the natural area of interest.
Product/Service Positioning	The target users are: Academic research community, industry with R&D units dedicated to modelling with first principles techniques.
Legal or normative or ethical requirements (need for authorisations, compliance to standards, norms, etc.)	None that we are aware of.
Competitors	Other research groups
Prospects/Customers	Academia

Cost of Implementation (before Exploitation)	We have proposed this new physical scenario, and shown it is realized in a simple model for V_2O_3. The next step should be showing it applies on models for other prototypical Mott insulators, proving it survives even if the models are made more realistic, and uncovering which consequences would arise. We estimate that three Post Doc fellowships might be sufficient, around €60000/year
Foreseen Product/Service Price	Unknown
Adequateness of Consortium Staff	The members of the Consortium can safely develop the scientific part. The possibility of exploitation (commercial or otherwise), however, would require special help on this area.
Status of IPR: Background (type and partner owner)	Not clear, yet
Status of IPR: Foreground (type and partner owner)	Not clear, yet
Status of IPR: Exploitation Forms (type and partner owner) e.g. direct industrial use, patenting, technology transfer, license agreement, publications, standards, etc.	Not clear, yet
Which partner contributes to what (main contributions in terms of know how, patents, etc.)	SISSA
Partner/s involved expectations	Partner expects to uncover interesting phenomena that derive from this new scenario of coexisting stable insulating and metastable metallic phases.
Sources of financing foreseen after the end of the project (venture capital, loans, other grants, etc.)	None Thinking about applying for another EU project

GROUP 3: PRODUCTS

KER7: DESIGN of 3D cryostat managing system

During the project we tackled the problem of developing a 3-degrees-of-freedom-mechanical handling system (manipulator) to control and move the closed-cycle cryostat employed for the low-temperature optical measurements. Since two mechanically decoupled parts that should be moved in a synchronized way constitute the cryostat, we developed a 6-motors synchronized manipulator that avoids transmitting the vibrations of the compressor to the sample, while leaving the freedom of moving the samples. The manipulator has been designed and assembled in our labs. The manipulator is controlled via homemade software written in the Labview (National Instruments) code.

Innovativeness introduced compared to already existing Products/Services	No such a tool is commercially available. Specific key scientific results have been implemented during the project. During the project, the UNICATT partner developed a mechanical handling for closed-cycle cryostat (ARSCryo) which enables the complete movement along the three main translational degrees of freedom (x,y,z), while maintaining the mechanical decoupling between the vibrating head and the cold finger. The 3 degrees of freedom linear translator are equipped with a motorized stage that is controlled by dedicated Labview software.
Unique Selling Point (competitive advantages)	The design of the mechanical handling system and the software for the remote control is the result of the research carried out in WP1 (Non-equilibrium states of correlated materials). The development of this handling system has been mandatory to perform low-temperature time-resolved measurements on high-temperature superconductors, which is the topic of WP4 (Optical manipulation of the superconducting-normal state phase transition).
Product/Service Market Size	The interest could range from research groups to private companies. The market for closed-cycle cryostats is dramatically increasing due to the cost of liquid He.
Market Trends/Public Acceptance	Possible positive trend due to the exponential increase of the closed-loop technology.

Product/Service Positioning	The target users are: Academic research community, industry with R&D units with interest in low-temperature measurements.
Legal or normative or ethical requirements (need for authorisations, compliance to standards, norms, etc.)	None that we know of.
Competitors	Companies producing high-vacuum and low-temperature equipment and accessories.
Prospects/Customers	Academia and private companies with R&D activities in the field of low-temperature measurements.
Cost of Implementation (before Exploitation)	The first complete prototype has been already implemented. The activity presents very low costs of implementation, since the various parts can be designed, ordered and assembled only when the customer requests it. The cost of the spare parts is estimated on the order of 10 k€. The competitiveness could be significantly increased in case of large-scale production.
Time to market	1-2 years
Foreseen Product/Service Price	Self-standing tool for simulation of the dynamics of local phase transition and for the calculation of the properties of engineered heterostructures.
Adequateness of Consortium Staff	The first complete (handling+motors+software) prototype has been developed by means of the expertise of the network in ultrafast optical spectroscopies.
External Experts/Partners to be involved	ARS-Cryo, 5Pascal
Status of IPR: Background (type and partner owner)	none
Status of IPR: Foreground (type and partner owner)	The knowledge developed during the development can be shared with the other experimental partners of the consortium. However, the original design of the system and the software will be protected by UNICATT, with the possible solution of releasing a temporal and cost-free license to the partners.
Status of IPR: Exploitation Forms (type and partner owner) e.g. direct industrial use, patenting, technology transfer, license agreement, publications, standards, etc.	The best protection strategy is currently under evaluation. A protection of design is probably the first step in this direction. We are evaluating the possibility of protecting the system handling+motors+software, while releasing a commercial license to a third part, namely 5Pascal that is the Italian distributor of ARSCryo.
Which partner contributes to what (main contributions in terms of know how, patents, etc.)	UNICATT mainly developed the tool
Partner/s involved expectations	Partners expect the tool to be commercially exploited.
Sources of financing foreseen after the end of the project (venture capital, loans, other grants, etc.)	Both the company producing the cryostats (ARS Cryo) and the Italian company that distributes them (5Pascal) expressed interest for this solution and for its commercialization. In the first stage, 5Pascal will anticipate all the costs necessary to develop and commercialize the firs items.

4.2 Use and dissemination of foreground

4.2.1 GO FAST: list of publications

1. D. Grieger and M. Fabrizio. Low-temperature magnetic ordering and structural distortions in vanadium sesquioxide (V2O3). ArXiv:1502.04555, (2015).

2. B. Mansart, D. Grieger, M. Fabrizio, V. Bal_edent, G. Lantz, N. Moisan, D. Boschetto, E. Papalazarou, A. Savoia, and M. Marsi. Ultrafast photo-induced non-thermal phonon hardening in the mott compound V2O3. Submitted to Nature Communications (2014).

3. A. Russomanno, R. Fazio, and G. E. Santoro. Thermalization in a periodically driven fully-
connected quantum ising ferromagnet. ArXiv:1412.0202 (2014).

4. A. Amaricci and M. Capone. Dynamical mean-_eld theory description of the voltage induced transition in a non-equilibrium superconductor. ArXiv:1411.2347 (2014).

5. S. Peli, S. Dal Conte, R. Comin, N. Nembrini, F. Banfi, G. Ferrini, S. Lupi, M. Capone, A. Damascelli, G. Cerullo, and C. Giannetti. *The room temperature prodrome of the quantum critical point in copper oxides.* In preparation (2015).

6. C. Giannetti, M. Capone, D. Fausti, M. Fabrizio, F. Parmigiani, D. Mihailovic. Ultrafast optical spectroscopy of strongly-correlated materials and high-temperature superconductors: a non-equilibrium approach**.** Invited review in **Advances in Physics** (2015).

7. G. Mazza, A. Amaricci, M. Capone, and M. Fabrizio. Electronic transport and dynamics in correlated heterostructures. **Phys. Rev. B. 91**, 195124 (2015).

8. D. Grieger and M. Fabrizio. *Low-temperature magnetic ordering and structural distortions in vanadium sesquioxide* (V_2O_3), (submitted). arXiv:1502.04555 (2015).

9. G. Mazza, A. Amaricci, M. Capone, and M. Fabrizio. *Electronic transport and dynamics in correlated heterostructures* (submitted). arXiv:1412.6415 (2014).

10. B. Mansart, D. Grieger, M. Fabrizio, V. Balédent, G. Lantz, N. Moisan, D. Boschetto, E. Pa- palazarou, A. Savoia, and M. Marsi. *Ultrafast photo-induced non-thermal phonon hardening in the mott compound V_2O_3*. Submitted to Nature Communications (2014).

11. A. Russomanno, R. Fazio, and G. E. Santoro. *Thermalization in a periodically driven fully- connected quantum ising ferromagnet* (submitted). arXiv:1412.0202 (2014).

12. A. Amaricci and M. Capone. *Dynamical mean-field theory description of the voltage induced transition in a non-equilibrium superconductor* (submitted). arXiv:1411.2347 (2014).

13. T. J. Huisman, R. V. Mikhaylovskiy, A. Tsukamoto, Th. Rasing, A. V. Kimel. *Revealing the role of orbital magnetism in ultrafast laser-induced demagnetization in multisublattice metallic magnets by terahertz spectroscopy* (submitted). arXiv:1412.5396 (2014).

14. R. V. Mikhaylovskiy et al. *Inverse magneto-refraction as a mechanism for laser modification of spin-spin exchange parameters and subsequent terahertz emission from iron oxides* (submitted). arXiv:1412.7094 (2014).

15. S. Dal Conte et al. *Snapshots of the retarded interaction of charge carriers with ultrafast fluctuations in cuprates*. Accepted for publication on **Nature Physics** (2015). arXiv:1501.03833 (2015).

16. M. Sandri and M. Fabrizio. *Non-equilibrium gap-collapse near a first-order mott transition*. **Physical Review B 91**, 115102 (2015).

17. D. Fausti, F. Novelli, G. Giovannetti, A. Avella, F. Cilento, L. Patthey, M. Radovic, M. Capone, F. Parmigiani, *Dynamical coupling between off-plane phonons and in-plane electronic excitations in superconducting YBCO*, (submitted). arXiv:1408.0888 (2014)**.**

18. R. V. Mikhaylovskiy, E. Hendry, V. V. Kruglyak, R. V. Pisarev, Th. Rasing, and A. V. Kimel. *Terahertz emission spectroscopy of laser-induced spin dynamics in $TmFeO_3$ and $ErFeO_3$ orthoferrites*. **Physical Review B 90**, 184405, 5 November 2014.

19. A. Maraga, A. Silva and M. Fabrizio, *Absence of thermalization in a Fermi liquid**,*** **Physical Review B 90**, 155131, 28 October 2014.

20. S. Sharma, A. Russomanno, G. E. Santoro, and A. Dutta. *Loschmidt echo and dynamical fidelity in periodically driven quantum systems*. **EPL (Europhysics Letters) 106**, 67003 (2014).

21. G. Borghi, M. Fabrizio and E. Tosatti, *Gutzwiller electronic structure calculations applied to transition metals: Kinetic energy gain with ferromagnetic order in bcc Fe*, **Physical Review B 90**, 125102, 02 September 2014.

22. A. Maraga, P. Smacchia, M. Fabrizio and A. Silva, *Nonadiabatic stationary behavior in a driven low dimensional gapped system*, **Physical Review B 90**, 041111(R), 29 July 2014.

23. F. Bencivenga, F. Capotondi, F. Casolari, F. Dallari, M. B. Danailov, G. De Ninno, D. Fausti, M. Kiskinova,M. Manfredda, C. Masciovecchio and E. Pedersoli, *Multi-colour pulses from seeded free-electron-lasers: towards the development of non-linear core-level coherent spectroscopies*, **Faraday Discussions 171**, 487-503, 21 July 2014.

24. F. Cilento et al., *Photo-enhanced antinodal conductivity in the pseudogap state of high T_c cuprates*, **Nature Communications 5**, 4353, 11st July 2014.

25. F. Bencivenga, E. Principi, E. Giangrisostomi, R. Cucini, A. Battistoni, F. D'Amico, A. Di Cicco, S. Di Fonzo, A. Filipponi, A. Gessini, R. Gunnella, M. Marsi, L. Properzi, M. Saito & C. Masciovecchio, *Reflectivity enhancement in titanium by ultrafast XUV irradiation*, **Scientific Reports 4**, 4952, 15 May 2014.

26. M. Esposito, F. Benatti, R. Floreanini, S. Olivares, F. Randi, K. Titimbo, M. Pividori, F. Novelli, F. Cilento, F. Parmigiani, D. Fausti, *Pulsed homodyne Gaussian quantum tomography with low detection efficiency*, **New Journal of Physics 16**, 043004, 7 April 2014.

27. G. Carleo, F. Becca, L. Sanchez-Palacio, and M. Fabrizio, *Light-cone effect and supersonic correlations in one- and two-dimensional bosonic superfluids,* **Phys. Rev. A 89**, 031602(R) 27 March 2014

28. F. Novelli et al., *Witnessing the formation and relaxation of massive quasi-particles in a strongly correlated electron system*, **Nature Communications 5**:5112, 7 March 2014.

29. J. D. Rameau et al*. Photoinduced changes in the cuprate electronic structure revealed by femtosecond time- and angle-resolved photoemission*, **Physical Review B 89**, 115115, 13 March 2014.

30. M. Hajlaoui et al. *Tuning a Schottky barrier with transient Dirac cone charge asymmetry in a photoexcited topological insulator*, **Nature Communications 5:**3003, 6 January 2014.

31. J. Faure et al. *Direct observation of electron thermalization and electron-phonon coupling in photoexcited bismuth*, **Physical Review B 88**, 075120, 12 August 2013.

32. J. Bnemann, M. Capone, J. Lorenzana, and G. Seibold. *Linear-response dynamics from the time-dependent gutzwiller approximation*. **New Journal of Physics**, 15, 053050 (2013).

33. S. de Jong et al; *Speed limit of the insulator–metal transition*; **Nature Materials 12**, 882-886, 28 July 2013*.*

34. M. Sandri and M. Fabrizio. *Non-equilibrium dynamics in the antiferromagnetic Hubbard model*; **Physical Review B 88**, 165113, 8 October 2013.

35. A. Russomanno, A. Silva, and G. E. Santoro. *Linear response as a singular limit for a periodically driven closed quantum system*. **Journal of Statistical Mechanics: Theory and Experiment**, 2013, P09012 (2013).

36. M. Behrmann, M. Fabrizio, and F. Lechermann; *Extended dynamic Mott transition in the two-band Hubbard model out of equilibrium*; **Physical Review B 88**, 035116, 15 July 2013*.*

37. F. Cilento et al. *In search for the pairing glue in cuprates by non-equilibrium optical spectroscopy*, **J. Phys.: Conf. Ser. 449**, 012003, 12 March 2013.

38. M. Sandri et al. *Finite-temperature Gutzwiller approximation and the phase diagram of a toy-model for* V_2O_3; **Physical Review B 87**, 205108**,** 8 March 2013.

39. F. Cilento et al. *In search for the pairing glue in cuprates by non-equilibrium optical spectroscopy*, **J. Phys**.: **Conf. Ser**. 449 012003; 12 March 2013.

40. S. Ziraldo, G.E. Santoro, *Relaxation and thermalization after a quantum quench: Why localization is important;* **Physical Review B 87,** 064201, 21 February 2013.

41. F. Novelli et al. *Mixed regime of light-matter interaction revealed by phase sensitive measurements of the dynamical Franz-Keldysh effect*. **Scientific Reports** 3:1227; 6 February 2013*.*

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4.2.2 GO FAST: list of dissemination actions

Type of activities	Main leader	Title	Date	Place
Dissemiantion action	SCUOLA INTERNAZIONALE SUPERIORE DI STUDI AVANZATI	Participation at the DPG Spring Meeting, By Daniel Grieger	14-21/03/2015	Berlin, Germany
Dissemiantion action	SCUOLA INTERNAZIONALE SUPERIORE DI STUDI AVANZATI	APS March meeting by Michele Fabrizio	28/02/2015	San Antonio USA
Dissemiantion action	SCUOLA INTERNAZIONALE SUPERIORE DI STUDI AVANZATI	PPT LEIT Modelling Policy Meeting	26-27/02/2015	Bruxelles, Belgium
Seminar	ALL	ESIC seminar. Seminar on exploitaiton organized by SISSA, with the participation of the consortium	19/02/2015	Trieste, Italy
Dissemiantion action	UNIVERSITAET DUISBURG-ESSEN	4th Banff meeting on structural dynamics by Uwe Bovensiepen, Klaus Sokolowski-Tinten	14/02/2015	Banff, Alberta, Canada
Particiaption at a workshop	UNIVERSITAET DUISBURG-ESSEN	LCLS-II Scientific Opportunities Workshop, attendace by Klaus Sokolowski-Tinten	08/02/2015	Menlo Park, CA
Oral presentation to a scientific event	STICHTING KATHOLIEKE UNIVERSITEIT	Talk: "Hz spectroscopy of femtomagnetism" at Physics@FOM 2015 by R. V. Mikhaylovskiy, A. V. Kimel	20/01/2015	Veldhoven, Netherlands
Oral presentation to a scientific event	STICHTING KATHOLIEKE UNIVERSITEIT	Talk "Rare-earth mediated optical control of magnetism" at Physics@FOM 2015 by R. V. Mikhaylovskiy, A. V. Kimel	21/01/2015	Veldhoven, Netherlands
Oral presentation to a scientific event	UNIVERSITA CATTOLICA DEL SACRO CUORE	"Snapshots of the retarded interaction of charge charriers with ultrafast fluctuations in cuprates" Invited talk at the International Workshop ”Dynamics of Quantum Many-body Systems far from Equilibrium” by Claudio Giannetti	14/12/2014	Krvavec, Slovenija
Oral presentation to a scientific event	UNICATT	"Unfolding the ultrafast relaxation processes in correlated materials by non-equilibrium spectroscopies" Invited talk at the International Workshop "Light pulses for investigating the time dimension across the fs ns scales: An integrated users facility of complementary Table Top Laser, Seeded Free Electron Laser and Storage Ring sources for time-resolved spectroscopies" by Claudio Giannetti	01/12/2014	Trieste, Italy

Type of activities	Main leader	Title	Date	Place
Cooperation in the organization of the Cluster Workshop	ALL	“Theory meets Industry”, the 27th-28th November 2014.	27-28/11/2014	Dublin, Ireland
Oral presentation to a scientific event	STICHTING KATHOLIEKE UNIVERSITEIT	Sub-picosecond optical modification of exchange parameters in antiferromagnetic transition metal oxides at the 59th Annual Magnetism and magnetic materials conference (MMM2014)	30/10/2014 07/11/2014	Honolulu, Hawaii
Oral presentation to a scientific event	UNIVERSITA CATTOLICA DEL SACRO CUORE	"Snapshots of the retarded interaction of charge charriers with ultrafast fluctuations in cuprates" Invited talk at the International Workshop on Probing and Understanding Exotic Superconductors and Superfluids by Claudio Giannetti	27/10/2014	ICTP Trieste, Italy
Oral presentation to a scientific event	UNIVERSITAET DUISBURG-ESSEN	"Non-equilibrium electronic structure of transient, laser-excited states in Bi-2212" intied toalk at Research Frontier of Transition-metal Compounds Opened by Advanced Spectroscopies by U. Bovensiepen	30/09/2014	Sendai, Japan
Oral presentation to a scientific event	UNIVERSITA CATTOLICA DEL SACRO CUORE	"Snapshots of the retarded interaction of charge charriers with ultrafast fluctuations in cuprates" Invited talk at the International Conference ”Correlations and Coherence at Different Scales” by Claudio Giannetti	05/09/2014	Ustron, Poland
Oral presentation to a scientific event	CENTRE NATIONAL DE LA RECHERCHE SCIENTIFIQUE	Ultrafast evolution of the prototype Mott-Hubbard compound V2O3 preswentation at JMC14-CMD25 Condensed Matter Div., by G. Lantz	24/08/2014	Paris (France)
Participation at summer school ELI Beamlines Summer School	UNIVERSITAET DUISBURG-ESSEN	ELI Beamlines Summer School ayttendace by Mohammadmahdi Afshari	24/08/2014	Prague, Czech Republic
Posters	UNIVERSITAET DUISBURG-ESSEN	Poster: "Time-resolved X-ray scattering on high TC superconductors" at ELI Beamlines Summer School 2014 by M. Afshari	24/08/2014	Prague, Czech Republic
Posters	UNIVERSITAET DUISBURG-ESSEN	Femtosecond time- and angle-resolved photoemission spectroscopy on Bi2212 above Tc using a position-sensitive time of flight spectrometer	10/08/2014	Corsica, France
Oral presentation to a scientific event	STICHTING KATHOLIEKE UNIVERSITEIT	"Terahertz spectroscopy of ultrafast spin synamics at the workshop on Brillouin and microwave spectroscopy of ultrafast spin dynamics" talk at the BrillMics 2014 by R. V. Mikhaylovskiy	03/08/2014	Saratov, Russia

Type of activities	Main leader	Title	Date	Place
Oral presentation to a wider public	CENTRE NATIONAL DE LA RECHERCHE SCIENTIFIQUE	Time-resolved optical spectroscopy on Na2IrO3 - Participation at the Summer School	03/08/2014	Nijmegen, the Netherlands
Participation in a summer schoo	UNIVERSITA CATTOLICA DEL SACRO CUORE	Summer School Multiscale Dynamics in Condensed Matter. Nicola Nemrbini. Focus on Time-resolved optical spectroscopy on Na2IrO3	03/08/2014	Nijmegen, the Netherlands
Oral presentation to a wider public	UNIVERSITA CATTOLICA DEL SACRO CUORE	Invited Lecture at the Summer School Multiscale Dynamics in Condensed Matter "Non-equilibrium spectroscopy of correlated materials and superconductors" by Claudio Giannetti	03/08/2014	Nijmegen, the Netherlands
Organisation of Summer school	STICHTING KATHOLIEKE UNIVERSITEIT	Summer School Multiscale Dynamics in Condensed Matter - Non-equilibrium spectroscopy of correlated materials and superconductors	03/08/2014	Nijmegen, the Netherlands
Oral presentation to a scientific event	SCUOLA INTERNAZIONALE SUPERIORE DI STUDI AVANZATI	"Thermalization in a Fermi Liquid", invited talk by Michele Fabrizio at the SCES14 International Conference on Strongly Correlated Electron Systems	07/07/2014	Grenoble (France)
Oral presentation to a scientific event	STICHTING KATHOLIEKE UNIVERSITEIT	Terahertz emission spectroscopy of ultrafast spin dynamics at the First international workshop on Novel trends in physics of Ferroics	04/07/2014	St. Petersburg, Russia
Oral presentation to a scientific event	STICHTING KATHOLIEKE UNIVERSITEIT	"Terahertz emission spectroscopy of ultrafast spin dymanics" invited talk at the NTPF 2014. R. V. Mikhaylovskiy, A. V. Kimel	04/07/2014	St. Petersburg, Russia
Oral presentation to a scientific event	STICHTING KATHOLIEKE UNIVERSITEIT	Optical manipulation of the super-exchange interaction on a sub-picoseconded timescale at Moscow International Symposium on Magnetism (MISM)	30/06/2014	Moscow, Russia
Oral presentation to a scientific event	UNIVERSITA CATTOLICA DEL SACRO CUORE	Snapshots of the retarded electron-boson interaction in high-temperature superconductors	30/06/2014	Leiden, The Netherlands
Oral presentation to a scientific event	UNIVERSITA CATTOLICA DEL SACRO CUORE	"Universal nature of antinodal pseudogap states in cuprates disclosed by non-equilibrium spectroscopies" Invited talk at the International Workshop ”(Towards) Room Temperature Superconductivity” by Claudio Giannetti	30/06/2014	Leiden, the Netherlands
Oral presentation to a scientific event	UNIVERSITA CATTOLICA DEL SACRO CUORE	"Universal nature of antinodal pseudogap states in cuprates disclosed by non-equilibrium spectroscopies" Invited talk at the International Conference Low Energy Electrodynamics in Solids (LEES2014) by Claudio Giannetti	29/06/2014	Loire Valley, France

Type of activities	Main leader	Title	Date	Place
Oral presentation to a scientific event	STICHTING KATHOLIEKE UNIVERSITEIT	"Optical manipulation of the super-exchange Interaction on a sub-picosecond timescale" at MISM 2014 by R. V. Mikhaylovskiy, A. V. Kimel	29/06/2014	Moscow, Russia
Oral presentation to a scientific event	SCUOLA INTERNAZIONALE SUPERIORE DI STUDI AVANZATI	"Gordon Research Conference on Correlated ElectronSystems" Conference, by Giacomo Mazza	22/06/2014	Mount holyoke Collegge South Hadley, USA
Oral presentation to a scientific event	SCUOLA INTERNAZIONALE SUPERIORE DI STUDI AVANZATI	The New Generation in Strongly Correlated Electron Systems 2014 Conference by Giacomo Mazza	16/06/2014	Nice, France
Oral presentation to a scientific event	CENTRE NATIONAL DE LA RECHERCHE SCIENTIFIQUE	Invited Talk - New Generation in Strongly Correlated Electronic Systems	16/06/2014	Nice, France
Oral presentation to a scientific event	SCUOLA INTERNAZIONALE SUPERIORE DI STUDI AVANZATI	Conference "Gutwiller Wave Functions and realted Methods" - Dissemination action by Michele Fabrizio	15/06/2014	Valence, France
Oral presentation to a scientific event	SCUOLA INTERNAZIONALE SUPERIORE DI STUDI AVANZATI	The new generation in strongly correlated electron systems 2014 Conference	15/06/2014	Nice, France
Oral presentation to a scientific event	UNIVERSITAET DUISBURG-ESSEN	"Non-equilibrium electronic structure of transient states in solid materials driven by femtosecond laser pulses" invited talk at Photo-induced phase transitions 5, by U. Bovensiepen	08/06/2014	Bled, Slovenia
Oral presentation to a scientific event	CENTRE NATIONAL DE LA RECHERCHE SCIENTIFIQUE	"Time resolved ARPES in strongly correlated materials" invited talk at the workshop MICO "Correlations in Materials" by Marino Marsi	26/05/2014	Grenoble (France)
Oral presentation to a scientific event	CENTRE NATIONAL DE LA RECHERCHE SCIENTIFIQUE	"Ultrafast dynamics of complex materials by time resolved ARPES" at SPLDS 2014 by Marino Marsi	21/05/2014	Nancy (France)
Posters	STICHTING KATHOLIEKE UNIVERSITEIT	Poster: “Terahertz spectroscopy of ultrafast processes in magnetic materials” at the IMM symposium 2014 by T. J. Huisman, R. V. Mikhaylovskiy, A. V. Kimel	19/05/2014	Nijmegen, Netherlands
Oral presentation to a scientific event	SCUOLA INTERNAZIONALE SUPERIORE DI STUDI AVANZATI	DPG Spring meeting	29/03/2014	Dresden, Germany
Oral presentation to a scientific event	UNIVERSITAET DUISBURG-ESSEN	Ultrafast changes in the electronic structure of solids investigated by time- and angle-resolved photoemission spectroscopy	13/03/2014	Irsee, Germany

Type of activities	Main leader	Title	Date	Place
Oral presentation to a scientific event	SCUOLA INTERNAZIONALE SUPERIORE DI STUDI AVANZATI	PPT LEIT Modelling policy meeting	26/02/2014	Bruxelles
Posters	UNIVERSITAET DUISBURG-ESSEN	Time- and angle-resolved photoemission of BSCCO above Tc: Transient Fermi surface changes and scattering rate analysis	04/02/2014	Ventura, CA, USA
Posters	STICHTING KATHOLIEKE UNIVERSITEIT	Gordon Conference on Ultrafast Phenomena in Cooperative Systems 2014	31/01/2014 11/02/2014	Ventura, USA
Oral presentation to a scientific event	UNIVERSITAET DUISBURG-ESSEN	Gordon Conference on Ultrafast Phenomena in Cooperative Systems 2014 by Uwe Bovensiepen	31/01/2014 11/02/2014	Ventura, USA
Posters	STICHTING KATHOLIEKE UNIVERSITEIT	Optical manipulation of the super-exchange interaction in iron oxides on a sub-picoseconded timescale	01/02/2014	Ventura, CA
Posters	STICHTING KATHOLIEKE UNIVERSITEIT	FOM Conference 2014	21/01/2014	Veldhoven, Netherlands
Oral presentation to a scientific event	UNIVERSITAET DUISBURG-ESSEN	Non-equilibrium dynamics in photo-excited low dimensional materials	17/01/2014	Jena, Univ.
Oral presentation to a scientific event	UNIVERSITA CATTOLICA DEL SACRO CUORE	Non-equilibrium optical spectroscopy: a new clue to unravel the properties of correlated materials	18/12/2013	Kravec, Slovenia
Oral presentation to a scientific event	SCUOLA INTERNAZIONALE SUPERIORE DI STUDI AVANZATI	Momentum- selective Mottness of the pseudo gap state of the cuprates revealed by time-resolved spectroscopy	19/12/2013	Krvavec, Slovenija
Oral presentation to a scientific event	SCUOLA INTERNAZIONALE SUPERIORE DI STUDI AVANZATI	Time-resolved spectroscopy reveals the momentum-selective Mottness of the pseudo gap state of the cuprates	21/11/2013	Tokyo, Japan
Oral presentation to a scientific event	UNIVERSITA CATTOLICA DEL SACRO CUORE	Conference on Frontiers of Condensed Matter Physics	11/11/2013	Trieste, Italy
Oral presentation to a scientific event	STICHTING KATHOLIEKE UNIVERSITEIT	Ultrafast Magnetism Conference 2013	01/11/2013	Strasbourg, France
Oral presentation to a wider public	STICHTING KATHOLIEKE UNIVERSITEIT	"Terahertz spectroscopy of utlrafast spin dynamics" at Ultrafast Magnetism Conference UMC 2013 by Mikhaylovskiy, R.	26-10-2013 03-11-2013	Paris, France

Type of activities	Main leader	Title	Date	Place
Oral presentation to a scientific event	SCUOLA INTERNAZIONALE SUPERIORE DI STUDI AVANZATI	Time-resolved spectroscopy reveals the momentum-selective Mottness of the pseudo gap state of the cuprates	18/10/2013	Trieste, Italy
Oral presentation to a scientific event	UNIVERSITAET DUISBURG-ESSEN	Ultrafast photo-induced changes in the electronic structure of Fe-pnictide and cuprate superconductors	17/10/2013	Trieste, Italy
Organisation of Workshops	SCUOLA INTERNAZIONALE SUPERIORE DI STUDI AVANZATI	ICTP - Ultrafast dynamics of correlated materials	14/10/2013	Trieste, Italy
Oral presentation to a wider public	UNIVERSITA CATTOLICA DEL SACRO CUORE	XCIX Congresso nazionale SIF - Non-equilibrium optical spectroscopy: a new clue to unravel the properties of correlated materials	25/09/2013	Trieste, Italy
Oral presentation to a scientific event	CENTRE NATIONAL DE LA RECHERCHE SCIENTIFIQUE	Invited talk - Topology, correlations and interfaces in quantum matter	16/09/2013	Orsay, France
Oral presentation to a wider public	STICHTING KATHOLIEKE UNIVERSITEIT	Joint European Magnetism Symposium JEMS 2013	25/08/2013 01/09/2013	Rhodes, Greece
Oral presentation to a scientific event	UNIVERSITAET DUISBURG-ESSEN	Femtosecond laser-induced changes of the cuprate Bi2212 electronic structure	19/08/2013	Dresden, Germany
Oral presentation to a scientific event	UNIVERSITA CATTOLICA DEL SACRO CUORE	International Workshop on Strong Correlations and Angle-Resolved Photoemission Spectroscopy (CORPES-13) - Non-equilibrium optical spectroscopy: a new clue to unravel the properties of correlated materials	29/07/2013	Hamburg, Germany
Organisation of Workshops	UNIVERSITA CATTOLICA DEL SACRO CUORE	The new generation in strongly-correlated electron systems	30/06/2013	Sestri Levante, Italy
Oral presentation to a scientific event	UNIVERSITAET DUISBURG-ESSEN	SNS2013 SNS meeting	28/06/2013	Berkeley, California USA
Oral presentation to a wider public	STICHTING KATHOLIEKE UNIVERSITEIT	International Symposium on Spin Waves 2013	13/06/2013	St. Petersburg, Russia
Oral presentation to a scientific event	STICHTING KATHOLIEKE UNIVERSITEIT	Wavefront workshop	06/06/2013	Hoenderloo, Netherlands
Posters	STICHTING KATHOLIEKE UNIVERSITEIT	IMM Symposium 2013	02/06/2013	Nijmegen, Netherlands

Type of activities	Main leader	Title	Date	Place
Oral presentation to a wider public	UNIVERSITA CATTOLICA DEL SACRO CUORE	Quantum in Complex Matter: Superconductivity, Magnetism and Ferroelectricity - Non-equilibrium optical spectroscopy: a new clue to unravel the properties of correlated materials	27/05/2013	Ischia, Italy
Oral presentation to a wider public	UNIVERSITA CATTOLICA DEL SACRO CUORE	Gordon Research Conference on Superconductivity - Non-equilibrium optical spectroscopy: a new clue to unravel the properties of correlated materials	12/05/2013	Les Diablerets, Switzerland
Oral presentation to a scientific event	STICHTING KATHOLIEKE UNIVERSITEIT	THz Focus Session	11/04/2013	Nijmegen, Netherlands
Publication	UNIVERSITA CATTOLICA DEL SACRO CUORE	In search for the pairing glue in cuprates by non-equilibrium optical spectroscopy	12/03/2013	-
Organisation of Workshops	UNIVERSITAET DUISBURG-ESSEN	Short-time Dynamics in Strongly Correlated Systems and Novel Superconductors	18/02/2013	Bochum, Germany
Oral presentation to a scientific event	UNIVERSITA CATTOLICA DEL SACRO CUORE	Short-time Dynamics in Strongly Correlated Systems and Novel Superconductors - Non-equilibrium optical spectroscopy: a new clue to unravel the properties of correlated materials	18/02/2013	Campus of the Ruhr-University Bochum, Germany
Publication	SINCROTRONE TRIESTE SCPA	Mixed regime of light-matter interaction phase sensitive measurements of the dynamical Franz-Keldys	06/02/2013	-
Oral presentation to a scientific event	UNIVERSITA CATTOLICA DEL SACRO CUORE	"Nonequilibrium phenomena in complex matter: new observations and new theories"	19/12/2012	Krvavec, Slovenia
Organisation of Workshops	UNIVERSITA CATTOLICA DEL SACRO CUORE	"Nonequilibrium phenomena in complex matter: new observations and new theories"	17/12/2012	Cerklje, Slovenija
Videos	UNIVERSITA CATTOLICA DEL SACRO CUORE	Inteview on the GO FAST Project	12/12/2012	Brescia, Italy
Press release	UNIVERSITA CATTOLICA DEL SACRO CUORE	Il progetto Go Fast disegna il futuro dell elettronica	12/12/2012	Brescia, Italy (web communication)
Press release	ELETTRA	GO FAST Project	30/11/2012	Trieste, Italy (web communication)