Project year 3 – Press release

The **aim of the GOFAST project** was to develop a joint theoretical-experimental effort to develop and test, for the first time, realistic non-equilibrium models for the ultrafast interaction of femtosecond light pulses with correlated electrons in transition metal oxides. The final goal was to achieve the ultrafast (<100 fs) control of the physical properties of these systems by photoinducing non-thermal final states with novel functionalities.

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 GO FAST project, full title: "Governing ultrafast the conductivity of correlated materials", was funded with 1,673,200.00 Euro granted by the European Commission within the 7th Framework Programme.

The project explored both experimentally and theoretically the non-equilibrium phase diagrams of two representative correlated materials, vanadium sesquioxide (V_2O_3) and copper-oxide superconductors in the BISCCO family, to ascertain whether intense and ultra short laser pulses allow driving phase transitions faster than heating and eventually stabilize transient metastable phases that are not accessible at equilibrium. Particular emphasis was placed to photo-induced transitions between phases with completely different conducting properties, Mott insulating versus metallic/superconducting, with the objective of identifying the non-equilibrium pathways between these phases hence the external parameters that one can exploit to better control those transitions (laser frequency, polarization and incidence angle).

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 exploit 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.

Among all results obtained by GOFAST consortium within the project, the most relevant are:

- The development of an efficient and flexible scheme to simulate the non-equilibrium dynamics of models for correlated systems within the Gutzwiller approximation, which does not require enforcing any constraint during the time-evolution.
- In the course of the project, it has become clear to us and to the scientific community that the gap between lower and upper Hubbard side bands in Mott insulators is as robust as the gap in conventional band insulators. Therefore it is not conceivable that an intense optical excitation could collapse that gap down and turn metallic the Mott insulator. 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 optically the system in the metastable metal phase, where it would stay trapped for times longer the closer the Mott transition. The main issue here is to identify the thermodynamic variable **M** that controls the first order transition (the equivalent of the density in the liquid-vapor 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 is indeed 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 bigger 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.

- Copper-oxide high-T_c superconductors are inherently particle-hole asymmetric, the more the lower the doping. In fact, the undoped compound is a typical charge-transfer Mott insulator, where additional holes go to oxygen while electrons to copper. In such a situation one can envisage that an 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 should the photo-excited state not be a thermal one. In the latter case, in fact, the change in chemical potential would correspond to that produced by increasing temperature, which does not lead to any notable phenomenon apart from obvious suppression of superconductivity. We have instead strong evidences that optical excitations across the charge-transfer gap do not bring to a thermal state. Indeed, we have observed that those excitations induce a non-thermal overpopulation of anti-nodal states, with sizeable lifetime, ≈ a picosecond, and pronounced metallic properties.

The aforementioned results that have been obtained during the three years of the project point to several research directions worth to be further pursued in the future. In particular, the non-thermal photo-induced behavior observed in 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, very often, strong first order character of known Mott transition, which are hitherto unexplored.

The success of the project is demonstrated also by the important number of publication in high impact factor journals, such as: 44 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 project will be kept alive through the GO FAST website, www.gofastproject.eu, which will continue to update the external audience on news related to the project's partners and on their research works.

The **GO FAST project** was coordinated by **Prof. Michele Fabrizio** of the Scuola Internazionale Superiore di Studi Avanzati - SISSA (Italy. The GO FAST project involves 7 entities from 4 EU Countries, each of them with specific roles within the project The consortium is composed by 4 Universities, 2 Research Centers and 1 SME.
The project was developed under the supervision of the EU Project Officer (PO) Anne De Baas and by the Project Technical Advisor (PTA) Richard Ball.

Project Partners

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