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Antonio Bianconi, Augusto Marcelli, Andrea Perali

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Metamaterials

Complex Quantum Matter

Fano Resonances

Book of Abstracts

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1. Transformation optics, surface plasmons, and metasurfaces

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Metallic surfaces support surface plasmon excitations whose properties are intimately connected to the surface geometry. For example a flat silver surface is an excellent mirror, but the same material with a rough surface is black, reflecting hardly any light. Here we use transformation optics to relate many complex surface structures to a single mother structure. In this way we can classify the spectra of these complex surfaces. Examples will be given of singular structures that harvest light, electron energy loss, van der Waals forces and other properties that are related to the surface plasmon spectrum.

2. Fluctuations and rare events

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In the study of biomolecules as well as in many other fields of science, computer simulations are pervasively used to solve difficult problems. However, very often the systems complexity makes the application of computer simulations challenging. Many systems of interest exhibit long lived metastable states separated by kinetic bottlenecks. In such cases, only very rarely occurring fluctuations allow the system to leave a metastable state. This makes the transitions from one state to another rare events. However, although rare, these events are crucial for a correct description of the system. For instance, phenomena such as nucleation, chemical reactions, and protein folding are a few examples of rare events. Unfortunately, the time scale of standard simulation falls short of what needed and the simulation of rare events is one of the main challenges of present day simulations. Here we present a novel approach to this problem, based on the introduction of a variational principle. We show how this variational principle can be used to study complex problems and calculate transition rates of rare events. We underline that besides offering computational efficiency this new approach provides a qualitative new point of view that will have far reaching consequences in the future

3. **Fano - Feshbach resonances in ultracold atomic physics**

Massimo Inguscio

Dipartimento di Fisica ed astronomia Università degli Studi di Firenze, Florence, Italy and President of CNR

4. Observation of anapole with dielectric nanoparticles

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- The possibility of the existence of non-radiating sources has attracted the attention of physicists for many years in different branches of science. One the of the intriguing examples is the so-called anapole moment proposed by Zel'dovich in connection with the radiation-less properties of a toroid solenoid. Furthermore, such electromagnetic configurations were recently suggested to classically describe the nature of dark matter. Here we demonstrate experimentally that dielectric nanoparticles can exhibit a radiationless anapole mode in visible. They provide new ways for excitation and investigation of the electro-magnetic properties of such nontrivial excitations

5. Computational schemes for optical response of hybrid systems composed of molecules, quantum dots and metallic nanoparticles

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Surface plasmons on a metal nanoparticle (MNP) can strongly localize light to subwave-length regions and greatly enhance the field in these regions. Gold nanoparticles, for example, are well known to exhibit plasmonic resonances in the visible. Hybrid systems of MNPs and semiconductor quantum dots (SQDs) are attracting special interest because interactions between the excitons of an SQD and the plasmons of an MNP can lead to novel effects and strong modifications of the optical properties of an SQD-MNP network compared to those of the underlying SQD or MNP building blocks. Exciton migration in a hybrid SQD-MNP network can be incoherent (diffusive) or coherent (wavelike). In the coherent case, excitations are transferred back and forth between the MNPs and the SQDs. This regime occurs in the vicinity of the exciton-plasmon resonance and produces a shift in the exciton emission frequency.

Coupling of the resonance to the broad continuum of plasmonic modes of the MNP in the presence of an applied driving field near the resonance has been investigated within the framework of the quantum density-matrix formalism, and is shown to yield Fano lines shapes, excitation induced transparency, and suppression and bistability behavior of the network.

The standard time dependent treatment can only include few building blocks since it involves a set of complicated nonlinear ordinary differential equations. In order to address this bottleneck in system size, we consider a set of linear von Neumann equations of motion in the steady state for the density matrix of each SQD placed in an effective field, due to the network, which is obtained within the discrete dipole approximation. The resulting equations differ sharply from the standard linear-response treatment in that our SQD density-matrix operator can be cast in terms of occupation numbers.

In this way, our method becomes extremely efficient and scalable and enables the treatment of very large hybrid networks [1]. Interestingly, the present models combining Quantum Mechanics and Maxwell's equations neglect the granular behavior of light needed to fully explain both the Compton and Raman effects. We will therefore consider a renormalization-group approach [2] to explain large Raman scattering cross sections from molecules on surfaces of metallic nanoparticles. In this approach the valence electrons of the molecules are embedded in an effective medium described by a dielectric function, which integrates out the effect of the plasmonic excitations of the metallic nanoparticles [3]. The source of the enhanced photon inelastic scattering is produced by the resonant excitation of surface plasmons at the metallic nanoparticles. Similar theories have been successfully used to explain the resonant x-ray inelastic scattering [4] and the behavior of nonlinear susceptibilities at the x-ray edges [5].

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6. Uncloaking topological phases in the Berezinskii-Kosterlitz-Thouless transition of Fermi superfluids: An interplay of spin-orbit coupling, Rabi fields and interactions.

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We investigate the Berezinskii-Kosterlitz-Thouless (BKT) transition in a two-dimensional (2D) neutral Fermi system with spin-orbit coupling (SOC), as a function of the two-body binding energy and a perpendicular Zeeman field [1]. By including a generic form of the SOC, as a function of Rashba and Dresselhaus terms, we study the evolution between the equal Rashba-Dresselhaus (ERD) and the Rashba-only (RO) cases. We show that in the ERD case, at fixed non-zero Zeeman field, the BKT transition temperature T_{BKT} is increased by the effect of the SOC for all values of the binding energy. We also find a significant increase in the value of the Clogston limit compared to the case without SOC. Furthermore, we demonstrate that the superfluid density tensor becomes anisotropic (except in the RO case), leading to an anisotropic phase-fluctuation action that describes elliptic vortices and anti-vortices, which become circular in the RO limit. This deformation constitutes an important experimental signature for superfluidity in a 2D Fermi system with ERD SOC. In addition, we show that the anisotropic sound velocity exhibit anomalies at low temperatures in the vicinity of quantum phase transitions between topologically distinct uniform superfluid phases. Finally, we discuss new results of more exotic superfluid phases which involve the coupling of "charge" and "spin" vortices [3] induced by the presence of spin-orbit and Zeeman fields.

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7. **BCS-BEC crossover in ultra-cold fermionic gases**

G. C. Strinati
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By the BCS-BEC crossover, the phenomena of superconductivity and superfluidity, which share the same kind of spontaneous symmetry breaking, are smoothly connected through the progressive reduction of the size of the fermionic pairs involved as the fundamental entities in both phenomena. This size ranges, from large values when Cooper pairs are strongly overlapping in the BCS limit of weak inter-particle attraction, to small values when composite bosons are non-overlapping in the BEC limit of strong inter-particle attraction. The idea behind the BCS-BEC crossover dates back just after the birth of the Bardeen- Cooper-Schrieffer (BCS) theory in 1957. The authors of this theory made a point to emphasize the differences between their theory for superconductors based on strongly-overlapping Cooper pairs and the Schafroth-Butler-Blatt theory resting on non-overlapping composite bosons which undergo Bose-Einstein condensation (BEC) at low temperature.
The BCS-BEC crossover has recently been realized experimentally, and essentially in all of its aspects, with ultra-cold Fermi gases. This is because a method was found to vary the scattering length a_F of the two fermion problem, from negative to positive values across the resonance where $a_F = \pm\infty$. For this reason, it appears fair to say that the BCS-BEC crossover should be considered as one of the main scientific achievements occurred over the last several years.
In this talk, emphasis will be given to the role played by the underlying Fermi surface in the evolution from the BCS to the BEC limits, which highlights the role of the finite particle density in the many-body problem with respect the two-body problem that defines the scattering length a_F. Theoretical calculations and related experimental data will be presented in this context.

8. Multigap superconductivity, shape and barrier driven resonances in superconducting nanofilms with an inner potential barrier

Andrea Perali [1, 2], Mauro M. Doria [1, 3], Marco Cariglia [1, 4]

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We study the crossover in a zero temperature superconducting nanofilm from a single to a double superconducting slab induced by a barrier in the middle. We use the Bogoliubov de Gennes (BdG) equations in the Anderson approximation to show that the single phase superconducting ground state of this heterostructure is intrinsically multigapped and has a new type of resonance caused by the strength of the barrier, thus distinct from the Thompson-Blatt shape resonance which is caused by tuning the thickness of the film. The simplest theoretical framework able to describe a finite height and very thin tunable insulating potential barrier in the middle is provided by a delta function potential. In this framework the even single particle states are affected by the insulating barrier, whereas the odd ones are not. The new type of resonance, hereafter called barrier driven resonance, is caused by the crossing of the even single particle states through the Fermi surface. The lift of the even-odd degeneracy at the barrier reconfigures the pairing interaction and leads to a multigapped superconducting state with barrier driven resonances.

9. Fano resonances and Cherenkov gluons in ultra-relativistic nuclear collisions

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It is argued that the experimentally observed phenomenon of asymmetric shapes of vector mesons produced in nuclear media during high energy nucleus-nucleus collisions can be explained as Fano-Feshbach resonances. It has been observed that the mass distributions of lepton pairs created at meson decays decline from the traditional Breit- Wigner shape with some excess in the low-mass wing of the resonance. It is clear that the whole phenomenon is related to some interaction with the nuclear medium. Moreover, it can be further detalized in quantum mechanics as the interference of direct and continuum states in Fano-Feshbach effect. To reveal the nature of the interaction it is proposed to use a phenomenological model of the additional contribution due to Cherenkov gluons. They can be created because of the excess of the refractivity index over 1 just in the low-mass wing as required by the classical Cherenkov treatment. In quantum mechanics, This requirement is related to the positive real part of the interaction amplitude in this wing. The corresponding parameters are found from the comparison with rho-meson data and admit reasonable explanation.
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10. The physics of jamming: a journey from marble pebbles toward scaling invariant field theory.

Giorgio Parisi
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Jamming is a well know phenomenon that you have experienced when the traffic if very heavy. You cannot move because your neighbors block you and your neighbors cannot move because you block them. Jamming is a collective phenomenon. Marble pebbles on the beach are one example of jamming. However also for well-levigated pebbles, friction will plays an important role. Statistical mechanics may be used to study the case of systems without friction. The most studied case is the hard sphere gas where the jamming point is reached in the limit of infinite pressure. In the case of frictionless jamming long-range correlations are present: we have a new kind of critical system. Recently the properties of the hard sphere gas have been analytically computed in the framework of the mean field approximation. Non-trivial critical exponents have been found. The behavior of the correlation functions at large distances has not yet computed (it is technically very challenging): at the end one should find a new scaling invariant field theory.

11. Brownian Motors: Spontaneous Pumping of Fluxons and Active Swimmers

Fabio Marchesoni

University of Camerino, Italy and Tongji University, P.R. China

The ratchet mechanism was investigated in the Nineties to explain the capability of certain cellular subsystems to sustain and direct molecular flows by rectifying environmental fluctuations. Such a mechanism requires the interplay of space and time symmetry. Inspired by biology, different classes of artificial micro- and nano-devices were designed with the purpose of controlling the transport of tiny objects along narrow channels. For instance, flows of magnetic vortices (aka fluxons) were generated by applying periodic (time asymmetric) transverse electric currents across type-II superconducting samples of appropriate (mirror asymmetric) geometries. Stronger ratchet currents have recently been predicted and actually observed by channeling active micro-swimmers, even in the absence of external time dependent perturbations. Active swimmers undergo persistent (ie, time correlated) Brownian motion and this property suffices to cause their rectification in the presence of spatial asymmetry. This presentation will focus on these two examples of biology-inspired nano-devices, the fluxon and the micro-swimmer pumps.

12. **Holographic duality, strange metals and entanglement.**

J. Zaanen
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The strange metals as observed in high T_c superconductors and other correlated electron systems are arguably the greatest enigma of condensed matter physics. The difficulties are rooted in the fundamentals of physics: the lack of a general mathematical framework to deal with strongly interacting fermions at finite density, the “fermion sign problem”. The holographic duality as discovered in string theory boils down to the remarkable fact that all of conventional condensed matter physics can be computed using the equations of generality relativity, but it is also the first method yielding a precise description of non-Fermi liquids [1]. These holographic strange metals are suggestively similar to the laboratory variety, at the same time defeating the basic principles of bosonic field theory. These are quantum critical phases with scaling properties alien to those computable with conventional methods. Remarkably their entanglement entropies demonstrate that their ground states are more densely entangled than deemed possible. I will present the case that this is rooted in a highly unconventional sign structure of these vacua.

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13. Hyperbolic Metamaterials

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Hyperbolic metamaterials were originally introduced to overcome the diffraction limit of optical imaging. Soon thereafter it was realized that hyperbolic metamaterials demonstrate a number of novel phenomena resulting from the broadband singular behavior of their density of photonic states. These novel phenomena and applications include super resolution imaging, new stealth technologies, enhanced quantum-electrodynamic effects, thermal hyperconductivity, superconductivity, and interesting gravitation theory analogues. I will review in more detail recent research on metamaterial superconductors and self-assembled three-dimensional hyperbolic metamaterials based on ferrofluids. Aluminum-based epsilon near zero (ENZ) and hyperbolic metamaterial superconductors exhibit superconducting critical temperature Tc that is three times that of pure aluminum. Promising fractal geometries of metamaterial superconductors will be discussed. I will also consider the recently suggested model of a multiverse based on a ferrofluid. When the ferrofluid is subjected to a modest external magnetic field, the nanoparticles inside the ferrofluid form small hyperbolic metamaterial domains, which from the electromagnetic standpoint behave as individual “Minkowski spacetimes” exhibiting different “laws of physics”, such as different strength of effective gravity, different versions of MOND and different radiation lifetimes. Thus, the ferrofluid-based metamaterial “multiverse” may be used to study models of MOND and to illustrate the fine-tuning mechanism.

14. **High temperature conventional superconductivity**

M. I. Eremets, A. P. Drozdov
Max Planck Institute of Chemistry, Mainz, Germany

We will present our recent results on the high temperature superconductivity up to 203 K[1] in different hydrides. The superconductivity has been proved by observation of zero resistance, Meissner effect, isotope effect, X-ray diffraction studies [2], and infrared and Raman studies. Results on studies of pure hydrogen also will be presented.
The observed apparently conventional superconductivity will be discussed in view of numerous theoretical works. Recent proposals of new superconducting materials and prospects for achieving higher critical temperatures of superconducting transition will be discussed too.

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15. **Hydrogen-rich materials under high pressure: towards room temperature superconductors**

Tian Cui

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Metallic hydrogen under high pressure is believed to be a room-temperature superconductor. However, there are no experimental evidence for the predicted metallic state in the pressure range up to 388 GPa. As an alternative, hydrogen-rich materials are extensively explored since their metallization can happen at relatively lower pressures because of chemical pre-compressions. Moreover, because such materials are dominated by hydrogen elements, most novel properties can be found after metallization, such as high-temperature superconductivity. Therefore, hydrogen-rich materials are expected to become a new member of superconductor family: hydrogen-based superconductor.

Here, we theoretically predicted H_3S with *Im*-3*m* symmetry to be a high-temperature superconductor with T_c reaching as high as 200 K at high pressure and proposed that H_3S can be formed at high pressure by two main ways: $3H_2S \rightarrow 2H_3S+S$, $2H_2S+H_2 \rightarrow 2H_3S$ [1]. Then, these results have been confirmed by in situ high pressure resistant transition, isotope effect, Meissner effect and synchrotron X-ray diffraction measurements[2-4]. Furthermore, we also explored the crystal structure and superconductivity in other hydrogen-rich materials at high pressures.

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16. **Multiband Superconductivity at extremely high temperatures: the case of pressurized sulfur hydrides**

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After the discovery of high temperature superconductivity in cuprates, the search for materials with even higher transition temperatures T_c was intensified, however, without success. Only recently the record T_c of 165K obtained in cuprates was broken by hydrogen sulfide under ultrahigh pressure, which reaches a T_c of 203K. This new discovery was motivated by theoretical considerations where an enhancement of T_c was predicted to take place in hydrogen containing compounds due to the light mass of hydrogen. Amazingly, the observed values of T_c>200K were rapidly classified as conventional, in the sense of BCS or Eliashberg theory whereas the first reports by Bednorz and Müller of T_c>30K immediately called for novel pairing interactions. Here we show that superconductivity in H_2S cannot be accounted for by using standard approaches, but that several electronic bands with substantially different character, namely polaronic and fermionic are involved in where important interband interactions are essential in obtaining the high values of T_c observed experimentally.

17. Pressure driven multi-condensates superconductivity at Lifshitz transitions in a complex spatial landscape with hyperbolic geometry

Subtitle: the emergence of macroscopic quantum coherence at room temperature

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While quantum mechanics was developed to explain the atomic world and high-energy physics in 1926, the macroscopic and low energy physics was assumed to be described by classical physics. However everyone can see that classical physics cannot describe the "physics of living matter" while life emerges in the macroscopic world in the temperature range between 200-400 Kelvin, i.e. (17-34 meV). Life is characterized by multiscale coherent phenomena from atomic scale 10^{-10} to 10 meters) and involves interactions in the low energy range (between 20 meV and few eV). The interest on superconductivity and superfluids has attracted a high interest in the scientific community in the XX century as a simple physical case of the emergence of quantum coherence in a many body system in the macroscopic world but at confined at very low temperature in the proximity of zero kelvin.

It is clear that a breakthrough toward our ignorance understanding the physics of living mater (the new physics of life in XXI century) is the discovery of room temperature superconductors

Material science has advanced our understanding in the field. I will present a summmary of the scenario where room temperature superconductivity has been driven by a Fano resonance between a first BEC-BCS and a second BCS condensate near a neck disrupting Lifshitz transition in a complex hyperbolic geometry spanning the spatial range from atomic to mesoscale.

The nanoscale phase separation (NPS) scenario with multiple electronic components called SUPERSTRIPES scenario [1] is a universal feature of high temperature superconductors [1-9]. NPS was observed using fast (10^{-15} s) and local (1 nm) probes : XANES EXAFS method [3-5] and confirmed by scanning nano x-ray diffraction [2]. The electrons fluctuate between puddles of charge density wave (CDW) phase and the superconducting phase [3].

In the superconducting phase the multiple electronic components form both first a BCS condensate and second condensate at the BEC-BCS crossover. In this complex landscape a new low energy quantum physics emerges on in the intermediate regime where localization and delocalization coexist in different portions of the k-space and real space. The key driving mechanism is the shape resonance in the configuration interaction between closed and open scattering channels that is the key quantum phenomenon which allows multi-condensates superconductivity, localized and delocalized pairs, with high critical temperature via exchange interaction [6]. The Lifshitz topological transition for a correlated electronic system in the presence of intrinsic and extrinsic disorder gives both phase separation [7,8,9,10,11] with CDW puddles [2] and shape resonance [6] in a complex geometry [2]. We propose that high temperature superconductivity emerges where shape resonances dominate in complex system in the intermediate regime where localization and delocalization coexist. Finally I will show that this scenario provide the explanation for superconductivity at 203K in the pressurized sulfur hydrides

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18. Novel high-pressure phenomena discovered through crystal structure prediction

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Recent methods of crystal structure prediction have opened wide opportunities for exploring materials at extreme conditions and perform computational screening for materials with optimal properties for various applications. In my laboratory, we have developed a very powerful evolutionary algorithm USPEX [1,2], enabling prediction of both the stable compounds and their crystal structures at arbitrary conditions, given just the set of chemical elements. Recent developments include major increase of efficiency and extensions to low-dimensional systems and molecular crystals [3] (which allowed large structures to be handled easily, e.g. $Mg(BH_4)_2$ [4] and H_2O-H_2 [5]) and a new technique called evolutionary metadynamics [6].
Some of the results that I will discuss include:
1. Theoretical and experimental evidence for a new partially ionic phase of boron, γ-B [7] and an insulating and optically transparent form of sodium [8].
2. Predicted stability of "impossible" chemical compounds that become stable under pressure – e.g. Na_3Cl, Na_2Cl, Na_3Cl_2, $NaCl_3$, $NaCl_7$ [9], Mg_3O_2 and MgO_2 [10].
3. Novel compounds in the C-H-O, N-H and Mg-Si-O systems, and implications for interiors of giant planets.
4. Novel compounds of helium, stable at experimentally reachable pressures, Na_2He and Na_2HeO.

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19. Pressure-induced novel structure and properties of halogen hydrides

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Hydrogen-rich materials can be metallized at much lower pressures due to "chemical pre-compression" and considered as good candidates for high T_c superconductors. Recently, both of theoretical and experimental reports on sulfur hydrides under pressure exhibiting high T_c with 200 K has inspired further efforts to research the superconductivity of hydrogen-rich materials.

Here, the structures, stability and superconductivity of halogen polyhydrides H_nX (X=F, Cl, Br and I) under pressure are studied using *ab initio* calculations. Triangular H_3^+ species are unexpected found in H_2F, H_3F, H_5F, H_5Cl and H_5Br compounds above 100 GPa. Importantly, formation process of H_3^+ species are clearly seen based on comparing bond length, BOP, ELF and Bader charge with pressure. Similar to H_2S, HBr decomposes into new hydrides H_2Br and Br_2 above 64 GPa. Further electron-phonon coupling calculations shown that that H_2Br are superconductors with T_c of 12.1 K at 240 GPa. Different from the other halogen hydrides, there is no H_3^+ species in hydrogen-rich H_nI (n=1~6). In H_2I-*R*-3m, H_2 molecular units disappear forming a atomic phase which has T_c of 33 K.

20. **The hydrogen bond role of hydrogen-rich compounds under high pressure**

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Since the realization of metallization and superconductivity in solid hydrogen is on the way, hydrogen-rich compounds are considered as good candidates for high T_c superconductors. The recent discovery of compressed sulfur hydrides with high T_c has inspired further efforts to research hydrogen-rich compounds. However, the behavior of hydrogen atoms in the hydrogen-rich compounds, especially the hydrogen-bond role, are still unclear.

The hydrogen bond is an attractive interaction between a hydrogen atom from a molecule or a molecular fragment D–H in which D is more electronegative than H, and an atom or a group of atoms in the same or a different molecule, in which there is evidence of bond formation. Here, with the typical examples of several hydrogen-rich compounds, we have studied their structural stability by using *in situ* high pressure experimental techniques, complementary with theoretical methods. By analyzing the crystal structures and properties of these compounds, the hydrogen-bond effect is discussed and explored in details, probably providing a new perspective of the hydrogen behavior under high pressure.

21. Pressure induced electronic topological transition : some case studies on the role of lattice degrees of freedom

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Pressure is an important thermodynamic parameter of primary interest in condensed matter as it permits to tune the strength of hybridization in a "clean" way. Indeed hydrostatic pressure can be used to tune the size and shape of the Fermi surface, resulting in a modification of its topology, leading to what is termed as electronic topological transition (ETT) [1]. The hexagonal close packed phase of iron undergo an ETT at about 40 GPa, leaving clear signatures also in the lattice parameter ratio *c/a* [2]. ETT is important in several class of correlated systems. Simplest three dimensional topological insulators like Bi_2Te_3 having insulating gap in the bulk and gapless edge in the surface, is found to show an ETT at a relatively low pressure about 4 GPa [3,4] leaving a clear signature also in the *c/a* ratio. A closely related system $AgBiSe_2$ is found to show a sudden drop in the electrical resistivity and anomalous changes in the Raman line width of the A_{1g} and $E_g^{(1)}$ modes around 2.8 GPa indicating the occurrence of an ETT [5]. Determination of accurate structural parameters under pressure is an important step in these research activities. Recently Elettra-Sincrotrone Trieste opened a dedicated high pressure diffraction facility "Xpress" [6] providing further infrastructure to these research directions. We have investigated the pressure dependent structural properties of an emerging two-dimensional system- black phosphorus [7] where an ETT is inferred at a relatively low pressure 1.2 GPa [8]. Use of the Xpress facility for the investigation of this of interesting topic will be briefly discussed.

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22. **Multiple Electronic Components in Cuprate High-Temperature Superconductors from NMR**

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As an atomic scale, bulk probe, nuclear magnetic resonance (NMR) must hold vital clues about the chemical and electronic properties of the cuprates, and NMR has influenced the field substantially over the years. However, due to the complex cuprate chemical structure, the presence of electronic inhomogeneity, and lack of field penetration in particular in the mixed state, NMR data and their interpretation are still incomplete. Recently, high-precision NMR experiments proved for various cuprate families that, contrary to early conclusions, a single electronic spin component cannot be supported anymore. Rather, the uniform response shows a Fermi liquid-like component that disappears below Tc, in addition to a pseudogap component that dominates the underdoped systems. There is even evidence for a third term that may originate from the coupling between the two spin components. Other recent NMR progress shows that the charge distribution in the copper-oxygen plane can be measured quantitatively. From it one concludes that the sharing of the inherent planar Cu hole with O is responsible for various properties, most notably it sets the maximum transition temperature. This charge transfer between Cu and O also affects the presence of the spin components as measured in Cu and O NMR experiments, and it may explain the differences in the spin response between different materials. Ubiquitous charge density variations are responsible for inhomogeneities in spin and charge.

23. **Intrinsic inhomogeneities in two-dimensional superconductors**

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Transition metal oxides are one of the hot topics of interest as these materials are endowed with a broad range of significant electronic properties ranging from ferroelectricity to metal-insulator transitions as well as from magnetism to superconductivity. In particular, experiments in oxide interfaces like $LaAlO_3/SrTiO_3$ or $LaTiO_3/SrTiO_3$ (LXO/STO) heterostructures, clearly indicate that the 2D electron gas and the resulting superconducting state at the interface is strongly inhomogeneous on the nanoscopic scale [1]. The self-consistent electrostatic electron confinement at the interface has recently been proposed as a possible mechanism of electronic instability [2] (possibly cooperating with the strong density-dependent Rashba spin-orbit coupling, RSOC observed in these systems, [3]). This leads to an electronic phase separation (EPS) establishing a possible intrinsic origin for the inhomogeneous character of LAO/STO or LTO/STO superconductors.
The inhomogeneous character of the 2DEG, accompanied by an inhomogeneous RSOC opens the way to two interesting classes of phenomena: i) a novel superconducting quantum criticality, and ii) inhomogeneous spintronics.

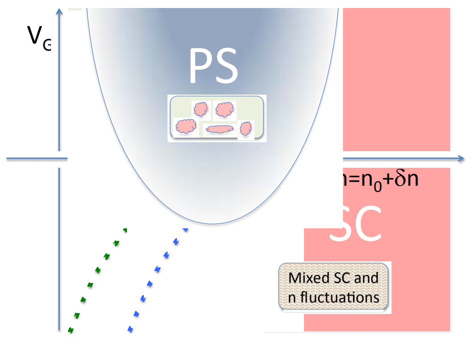

Fig. 1 from Ref. 5 Schematic phase diagram of the LXO/STO interface. Differently prepared samples follow the different dotted lines upon changing the backgating potential

i) The unusual quantum critical behaviour of superconductivity in LXO/STO [4-6] has been investigated by tuning temperature, gating, and/or magnetic field finding a novel type of SC-to-metal quantum criticality related to the vanishing of the critical temperature of the EPS [5,6], where the critical superconducting fluctuations are coupled to and driven by the strong dynamical density fluctuations. The possible occurrence of a Griffith phase has also been found.
ii) The softness of the 2DEG allows an easy designing of specific structures where the RSOC can be modulated at the submicrometric scale. This opens the way to a variety of 2DEG structures, where spin-Hall effect [7], (inverse) Edelstein effect, and Majorana Fermions [8], could be obtained.

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24. The soft side of hard matter

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I will show a recent example where soft condensed matter effects emerge on a hard matter system, namely the low-doping regime of cuprate superconductors. We show that in these materials electrons form polymers of charge accompanied by a non-trivial topological structure of the surrounding "solvent" played by antiferromagnetic regions. These electronic polymers can order in orientation (and direction) as the soft-matter liquid crystal phases (Figure 1). Within a Monte Carlo study, we find that in clean systems by lowering the temperature the polymer melt condenses first in a smectic state and then in a Wigner crystal both with the addition of inversion symmetry breaking. Disorder blurs the positional order leaving a robust inversion symmetry breaking and a nematic order (called ferronematic), accompanied by vector chiral spin order and with the persistence of a thermodynamic transition. Such electronic phases, whose properties are reminiscent of soft-matter physics, produce charge and spin responses in good accord with experiments and reconcile the phase diagram of cuprates with other unconventional superconductors. Work done in collaboration with: M. Capati, C. Di Castro, M. Grilli, S. Caprara, G. Seibold

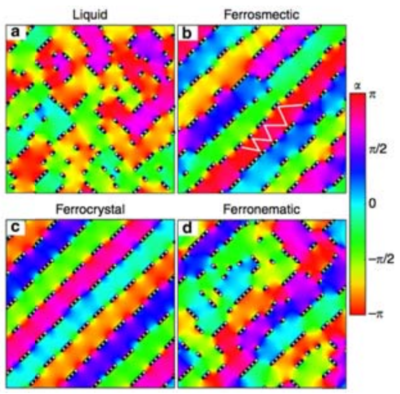

Fig. 1: Liquid crystal like electphases in underdoped cuprates

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25. **Spin Hall Effect by Phonon Skew Scattering**

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The spin Hall effect, first predicted in 1971 by Dyakonov and Perel, is the generation of a spin current in response to an applied electric field. This effect, which arises as a consequence of spin-orbit coupling, is now at the forefront of spintronics research, which aims to develop new device functionalities based on spin-charge conversion mechanisms.

In particular, in recent years the spin Hall effect has been studied extensively in metallic bilayers made of a ferromagnet and a heavy normal metal. In a real system, the spin Hall effect can have several origins due to the different microscopic mechanisms through which the spin-orbit coupling may be active.

In this talk I will present recent results on the spin Hall effect due to the skew scattering mechanism mediated by phonons. Such a mechanism yields a well defined prediction for the temperature dependence of the effect. After a brief review of the experimental situation,

I will sketch the theory of the effect. In the final part I will also report on some recent experimental results, which appear to be compatible with the theoretical predictions. The results presented are based on joint work with C. Gorini and U. Eckern and have been published in PRL 115, 076801 (2015).

27. **Fano effect in exotic plasmonic materials: The case of Topological Insulators and High-Tc Superconductors**

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Plasmons, the collective oscillations of electrons in metals, show notable properties like a strong interaction with the electromagnetic field, a reduced wavelength in comparison with that of exciting light and a huge electric field enhancement. Those properties are at the basis of surface-enhanced Raman and Infrared spectroscopies which are now routinely used in many bio-sensing applications. However, in looking for tunable and active devices, plasmonics should be based on more exotic materials like graphene, Topological Insulators and Superconductors. In this talk, I will discuss a couple of examples of plasmonic metamaterials working in the Terahertz range and based on Bi_2Se_3 Topological Insulator and YBaCuO and MgB_2 High-Tc Superconductors where a prominent Fano effect can be observed and modulated by pulsed light and temperature.

28. Boson Sampling with integrated quantum photonics

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Integrated photonic circuits have a strong potential to perform quantum information processing. Indeed, the ability to manipulate quantum states of light by integrated devices may open new perspectives both for fundamental tests of quantum mechanics and for novel technological applications.

The evolution of bosons undergoing arbitrary linear unitary transformations quickly becomes hard to predict using classical computers as we increase the number of particles and modes. Photons propagating in a multiport interferometer naturally solve this so-called *boson sampling* problem, thereby motivating the development of technologies that enable precise control of multi-photon interference in large interferometers. We implemented a small instance of the boson sampling problem by studying three-photon interference in a 13-mode integrated interferometer, confirming the quantum-mechanical predictions. Scaled-up versions of this set-up are a promising way to demonstrate the computational advantage of quantum systems over classical computers. Furthermore we report a new variation of this task, *scattershot boson sampling*, which leads to an exponential increase in speed of the quantum device, using a larger number of photon sources based on parametric down-conversion.

29. **Non-equilibrium quantum materials.**

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Femtosecond time-resolved spectroscopy techniques are emerging tools in the study of quantum materials, offering new paths to disentangle coexisting phases with similar energy scale. In this talk I will present non-equilibrium time and angle resolved photoemission studies of cuprate superconductors and topological insulators. I will focus on the momentum dependent dynamics of quasiparticles at short and long delay time, as well as on the time and momentum evolution of the superconducting gap and pseudogap. I will discuss a scenario in which recombination of Cooper pair in a superconductor is dominated by stimulated emission process.

Finally, I will also present some results of how this approach can provide new information on the formation of topologically protected surface states in TI.

30. **Nanoscale phase separation and lattice complexity in VO2, a complex multiphase correlated electron systems**

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The appearance of spatially separated regions with distinct structural, magnetic, and electronic properties is described as a (dynamic) phase separation that occurs where two or more phases with comparable free energies and a large coherence length coexist. The heterogeneity may extend in the mesoscale with domains ranging from the atomic scale to

The micron-scale. An arrested phase separation is typical of transition metal oxides where two or more phases form complex textures. All domains play a role in the dynamics of the observed phenomena such as phase transformations, transport, magnetic and structural changes, and are at the origin of the strong anomalies in the properties characteristic of phase-separated systems.

Transition metal oxides offer a wide spectrum of examples of phase-separated systems where anomalies can be observed in different observable quantities such as the resistivity and/or the optical transmission. These phenomena originate from interactions among spin, lattice, and charge degrees of freedom.

Among the TM systems the vanadium dioxide (VO_2) is certainly one of the most challenging and studied systems because it undergoes upon heating or cooling through a temperature range near room temperature (~340 K), to a hysteretic metal–insulator transition and a structural phase transition from monoclinic to rutile phases, with a change in conductivity by several orders of magnitude.

The change corresponds to V− V dimerization along the c axis forming homo-polar bonds associated to a structural twist of edge-sharing octahedrons. An electron-correlation-driven Mott transition and a structure distortion-driven Peierls transition, or cooperation of two mechanisms, have been proposed to explain the insulator to metal transition. However, in spite of decades of great efforts the driving mechanism of the MIT transition remains an open question.

High-resolution XANES spectroscopy has the sensitivity to probe the local structure and the electronic changes associated with a MIT transition. Moreover, a local probe such as XANES may investigate simultaneously both the metal–insulator transition and the structural phase transition.

We will discuss the existing scenario with experiments performed on VO_2 films using XAS, photoemission, optical and transport measurements at different temperatures. In particular, we will report preliminary results of Resonant Photoemission data trying to describe the dynamics of the different atomic contributions of the DOS of VO_2.

31. Curvatronics with bilayer graphene in an effective 4D spacetime

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We show that in AB stacked bilayer graphene low energy excitations around the semimetallic points are described by massless, four dimensional Dirac fermions. There is an effective reconstruction of the 4 dimensional spacetime, including in particular the dimension perpendicular to the sheet, that arises dynamically from the physical graphene sheet and the interactionsexperienced by the carriers. The effective spacetime is the Eisenhart-Duval lift of the dynamics experienced by Galiei invariant L´evy-Leblond spin 1/2particles near the Dirac points. We find thatchanging the intrinsic curvature of the bilayer sheet induces a change in the energy level of theelectronic bands, switching from a conducting regime for negative curvature to an isolating onewhen curvature is positive. In particular, curving graphene bilayers allows opening or closing the energy gap between conduction and valence bands, a key effect for electronic devices. Thus using curvature as a tunable parameter opens the way for the beginning of curvatronics in bilayer graphene.

32. Evidence for strong lattice effects as revealed from huge unconventional oxygen isotope effects on the pseudogap temperature in $La_{2-x}Sr_xCuO_4$

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The oxygen isotope ($^{16}O/^{18}O$) effect (OIE) on the pseudogap (charge-stripe ordering) temperature T* is investigated for the cuprate superconductor $La_{2-x}Sr_xCuO_4$ as a function of doping x by means of x-ray absorption near edge structure (XANES) studies. A strong x dependent and sign reversed OIE on T* is observed. The OIE exponent $\square_{T^*}$ systematically decreases from $\square_{T^*}$ = - 0.6(1.3) for x = 0.15 to $\square_{T^*}$ = - 4.4(1.1) for x = 0.06, corresponding to increasing T* and decreasing superconducting transition temperature T_c. Both $T^*(^{16}O)$ and $T^*(^{18}O)$ exhibit a linear doping dependence with different slopes and critical end points (where $T^*(^{16}O)$ and $T^*(^{18}O)$ fall to zero) at $x_c(^{16}O) = 0.201(4)$ and $x_c(^{18}O) = 0.182(3)$, indicating a large positive OIE of x_c with an exponent of $\square_{xc}$ = 0.84(22). The remarkably large and strongly doping dependent OIE on T* signals a substantial involvement of the lattice in the formation of the pseudogap, consistent with a polaronic approach to cuprate superconductivity and the vibronic character of its ground state.

33. Complexity in heterogeneous functional materials as seen by synchrotron x-ray (sub)micron beam techniques

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Outstanding structure-function relationship of new functional materials are often due their dynamic heterogeneous structure and composition [1, 2]. Strongly electrons correlated materials constitute an important class of materials showing intriguing properties. The competition between competing orders due to defects spatial distribution and electronic textures gives mesoscale phase separation that is believed to play a central role for material functionality [3]. Taking advances from X ray synchrotron radiation features and from optical focusing devices, we can visualize this nanoscale phase separation with fine details in real space. The results suggest a complex scenario where HTS emerges in networks competing with electronic textures at mesoscale. We also show the possibility to extend our methodology to visualize complex and heterogeneous structures at nano/mesoscopic scale in different fields from material science to biomedicine [4, 5].

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34. Early cancer diagnostics by IR-SNOM spectroscopy

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We present a fully implemented Infrared (IR) Scanning Near-field Optical Microscopy (SNOM) in spectroscopic mode for tissue imaging and early cancer diagnostics. The SNOM has been coupled with an infrared light source, based on Free Electron Laser at the ALICE facility in Daresbury [1]. Results of IR-SNOM on oesophageal adenocarcinoma have shown that the system can operate at nanometer resolution and has been able to distinguish between healthy and malignant tissues [2]. The optical fibre has been driven in particular areas of the oesophageal tissue and topographical and optical images have been collected simultaneously at different wavelengths (protein/glycoprotein, DNA). This combination of InfraRed radiation and Scanning Near-field Optical Microscopy, in its spectroscopic mode, can be an important tool for tissue imaging and early cancer diagnostics. It is expected to produce a major advance in imaging of malignant tissues [3], leading to the development of portable diagnostic devices for hospital use for various types of cancer. It is also planned to utilise the powerful combination of high spatial resolution and chemical specificity of the mentioned methodologies to study the key components, responsible for cancer formation.

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POSTERS

35. X-ray Magnetic Dichroism spectroscopy at Cu *K*-edge and *L*-edge of Bi2212 superconductors

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Key words: XMCD, Cu K-edge, L-edge, Bi2212

The circular dichroism in absorption can be induced by either the nonmagnetic effect in electic dipole-quadrupole (E1-E2) channel (XNCD) or by magnetic signal in E1-E1 channle (parity-even XMCD). There is a debate[1] over the nature of the circular dichroism (whether is it XNCD or XMCD) in Bi2212, which possesses strongly anisotropic layered and incommesurate structure ; the latter had been under controversy over decades. There were lots of crystallographyic investigations using X-ray or neutron diffractions attempting to describe its incommesurate modulated structure more accurately. [2-10] The emergence of charge density wave and stripes structures that is believed crucial for superconductivity is all related to complexity in the crystallographic structure. Hence it is still of great interests to investigate the structural in details. Herein, we performed theoretical calculations of the X-ray dichoism absorption at Cu *K*-edge and *L*-edge using different crystallographic structures. It is found that the crystallographic structures as reported in literatures could not describe the true structures of Bi2212. From the theoretical calculations, it is found that:

1) the X-ray dischroism signal is more senstive to the symmetry breaking of the local coordinates than XANES or its first derivative spectrum.

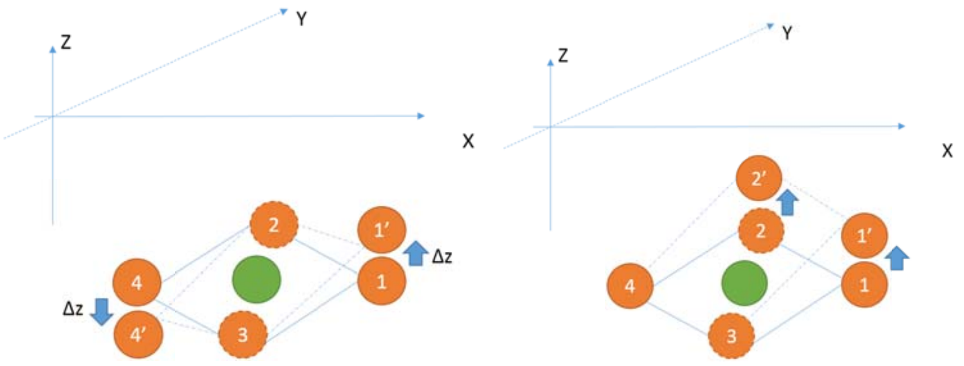
2) the XMCD signal can be evident above 10^{-4} for the rhobic distortion (with respect to CuO_4 square plane) of the oxygen coordination, i.e. when two oxygen atoms (sitting in the diagonal of square) are moving out of plane. Figure.1(a)

3) the XMCD signal is quite weak ~10^{-6} or 10^{-7} for the rectangular disortion (with respect to CuO_4 square plane) of the oxygen coordination, i.e. when two adjacent oxygen atoms are moving either up or down simulatenously.

4) with rhombic distortions, the peak position of maximum peak XMCD shifts towards lower energy as the absolute value of z for two oxygen atom (sitting in the diagonal of square) increases from 0.2 angstrom to 0.6 angstrom.

6) with rhombic distortions, the XMCD signal of the maximum peak increases as the absolute value of z for two oxygen atom (sitting in the diagonal of square) increases from 0.2 angstrom to 0.6 angstrom.

Hence it is important to verify the intensity as well as the peak position of the maximum peak in XMCD signal in Bi2212 so as to understand the local structural symmtry, parity breaking very well, which is believed to be correlated with the origin of the superconductivity of this sytem.



(a) rhombic distortion (b) rectangular distoriton

Figure.1 The distortions of the local oxygen coordinates (a) with two diagnonal oxygen atoms moving respectively up and down ; and (b) with two adjacent oxygen atoms moving either up or down.

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36. **BEC-BCS crossover in a multiband double bilayer graphene**

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Several experimental and theoretical e_orts have been done to search and to generate electron-hole superuidity in a bilayer graphene and in related nano-thin materials. Recently a new system has been theoretically demonstrated to be able to access the regime of strong pairing necessary for super We investigate the BCS-BEC crossover in a system consisting of two parallel bilayers graphene separated by a hBN insulating layer[2]. We use the mean field approximation at zero temperature for multiband systems with intra-band pairing. We present results for the two bands gap equation as function of the chemical potential and the Fermi energy. We introduce the energy band gap as parameter and we investigate how it a_ects the pairing. We characterize the crossover with the new parameter studying the condensate fraction as function of the carriers density. Our fundings and new experimental results establish double bilayer graphene as an ideal system in which to study the rich phase diagram of strongly interacting particles and call for further theoretical investigations.

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37. **Quantum-size effects in superconducting nanostripes with step-edge**

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When the dimensions of a superconductor are of the order of the Fermi wavelength, the superconducting properties are influenced by quantum confinement that discretes the energy levels near the Fermi level, leading to the variation of the density of states, and induces a reconfiguration of the pairing interaction leading to multigap effects. Therefore the number of Cooper pairs and the superconducting energy gap become dependent on the size and the shape of the specimen, i.e., quantum-size effects and shape resonance effects. In this regime we expect quantum-size oscillations in Tc and the superconducting order parameter accompanied by enhancement of superconductivity. The microscopic Bogoliubov-de Gennes (BdG) equations are a theoretical starting-point for nanoconfined systems. Results contain information on the full quasi-particle energy spectrum so that they can be compared with scanning tunneling microscopy (STM) experiments. Our goal is to investigate the effect of a step edge in superconducting nanostripes. Recently, its effect was found to be pronounced in experiments on ultrathin superconducting films [1]. Here, we show that the step edge induces scattering on quasiparticle states and how it causes important modifications on the order parameter and the local density of states.

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38. Crosspairing Effects in a Two Band Superconductor

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We investigate the crosspairing in a system with two identical bands. Using the Gor'kov-Nambu Green's function formalism we obtain expressions for the gaps due to intraband and interband pairing [1]. We found that there is not coexistence of solutions in the absence of Josephson-like transfer of Cooper pairs for the crosspairing [2]. This is because the interband pairing and the crosspairing are competitive. However, for some degenerate cases we found two coexistent solutions: one with all bands identical and other with a phase shift between the two bands. The later case indicates that scattering of Cooper pairs in the intraband and interband case are mutually transferable. Finally we discuss the experimental signature of the crosspairing for different materials.

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39. **Electronic and optical properties of Weyl semimetals based on transition metal monopnictides: Ab initio studies of TaAs, TaP, NbAs and NbP**

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We investigate electronic, optical and loss properties of the newly discovered Weyl semimetals TaAs, TaP, NbAs and NbP[1-4] crystallizing in bct geometry for small and larger energies by means of the ab initio density functional theory with spin-orbit interaction and within the independent-particle approximation. Chemical trends are discussed. The four band structures show well energetically separated Ta5d/Nb4d conduction and As4p/P3p valence bands. Their small energetical overlap leads to electron and/or hole pockets near the Fermi energy ε_F at the 8 W1 and 16 W2 Weyl nodes, the parameters of which are computed, in particular for the linear bands and the small energy distances between ε_F and the Weyl nodes. The bands and their occupation near the Weyl nodes determine the infrared optical properties. They give rise to almost constant values of the imaginary part of the dielectric function and, hence, a linear increase of the real part of the optical conductivity. The high-energy spectra are dominated by interband transitions in the band structure. The energy zeros of the real part of the dielectric function define plasmon frequencies, at which the energy loss function exhibits a pronounced peak. Whereas the details of the Weyl nodes are compared with recent ARPES results for TaAs and NbP, we directly compare with measured optical spectra for TaAs[5].

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40. **Hybrid CIGS: TiO_2 thin film solar cells by sol gel method.**

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Key words: thin film, photovoltaic cell, CIGS, TiO2

The preparation of photovoltaic thin cells is a fundamental step forward in the PV technology to reduce the global cost and will probably be the most important area of this technology, but is still very difficult to prepare thin film PV with a good efficiency (more than 10%) with industrial processes in order to make this technology available to the market. Most of the thin film PV are well prepared using high vacuum deposition techniques, as PVD or PED, in contrary no HV techniques as chemical bath deposition can't reach the same quality of preparation and often some type of layers can't be deposed with chemical bath techniques [1,2].

One of the most common thin film absorber layer in PV is CIGS, because of his very high absorption coefficient it can be deposited also thin enough in order to use flexible substrates. Usually a ZnO as n-type layer has to be deposited using high vacuum techniques [3].

Is possible to replace the ZnO layer with another common n-type buffer layer, as titanium dioxide. In the present work we realize a solar cell depositing both materials cigs and TiO_2 without using vacuum process, only chemical and thermal preparations by means of sol gel method.

In the figure 1 is shown the solar cell with an active area of 5x5 mm2. We also characterized the cigs thin film with XRD to obtain the best recipe (figure 2). From photocurrent spectrum (figure 3) we observe a wide range of the absorbance of the cigs cell that is responsible of the high efficency of this material.

References

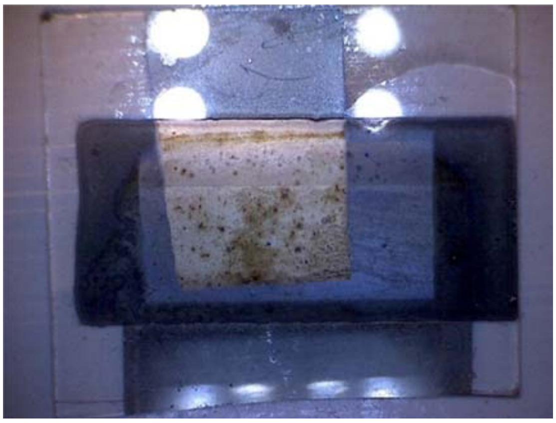

Figure 1. Picture of hybrid cigs:TiO_2 cell.

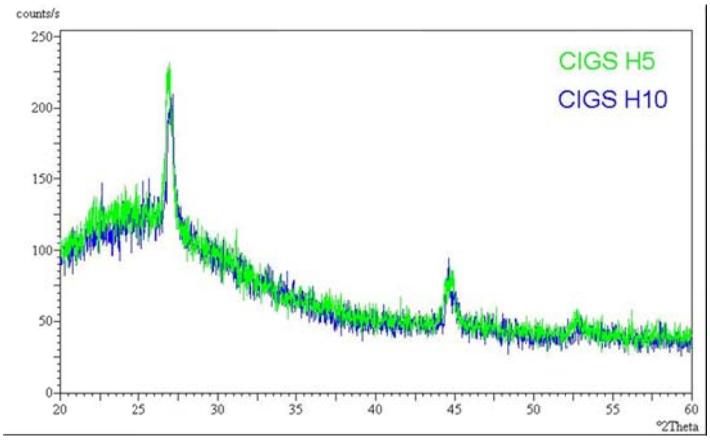

Figure2. XRD on film annealed at different temperature : H5 =450°C; H10 =550°C.

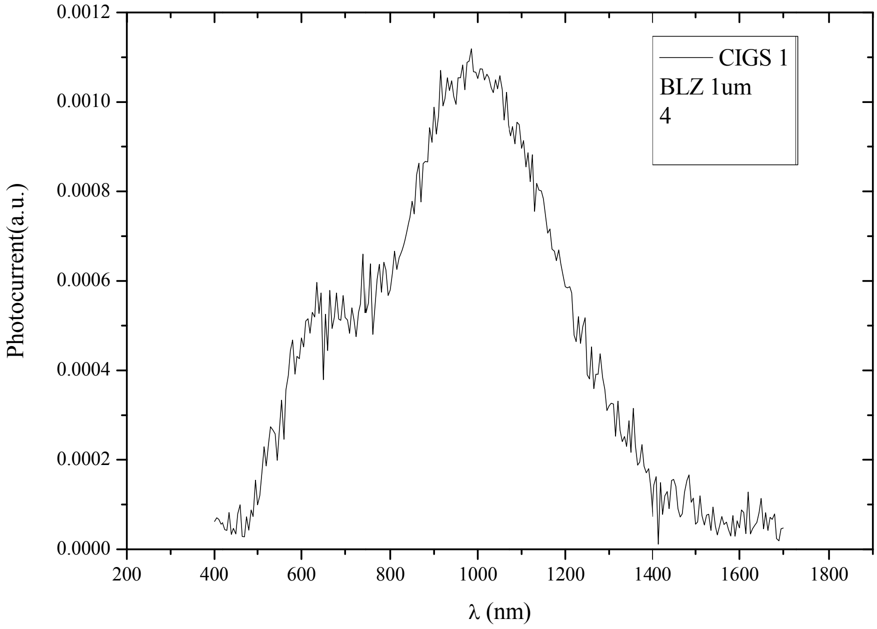

Figure3. Photo current spectrum of the hybrid cigs:TiO_2 cell.

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41. ***MOST***: ***MO*****lecular *S*cience and *T*echnology.-A new XUV beamline at Elettra, Trieste**

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We will briefly outline the project MOST, "*MO*lecular *S*cience and *T*echnology", for the realization of a novel undulator-based beamline for studies of isolated species (atoms, molecules, clusters and nanoparticles), chirality, liquids and adsorbate systems. The project has been recently approved by the Elettra Scientific Advisory Committee. Within the well-established collaboration between Elettra-Sincrotrone Trieste and CNR (ISM and IOM), MOST combines the scientific interests of the atomic and molecular physics community presently working at the Gas Phase Photoemission beamline (GasPhase) and the Circular Polarization beamline (CiPo). The MOST beamline will also constitute a facility very well suited to cutting edge investigations of the electronic structure of organic semiconductor materials, starting from their molecular building blocks to deposited films. The beamline will be "Elettra2-ready", using state-of-the-art optical design and technology to reach higher performance than is available at Elettra today.

The main scientific program is based around

- Strengthening of the lines of research at the CiPo and GasPhase, with more emphasis on bio and complex organic molecules
- Circular dichroism of chiral systems
- Pump-probe with optical laser
- Liquid state spectroscopy, with emphasis on pump-probe experiments
- Studies of free nanoparticles.

Technical specifications include

- Polarization control via modern Apple type undulators
- Wide energy range from 8 eV to above 1 keV
- Suppression of harmonics at low energy (aperiodic undulator; grating design)
- High flux due to efficient undulator design, modern optics (Variable Line Spacing/groove depth, etc.)
- Integrated design, allowing efficient use of optical laser for pump-probe