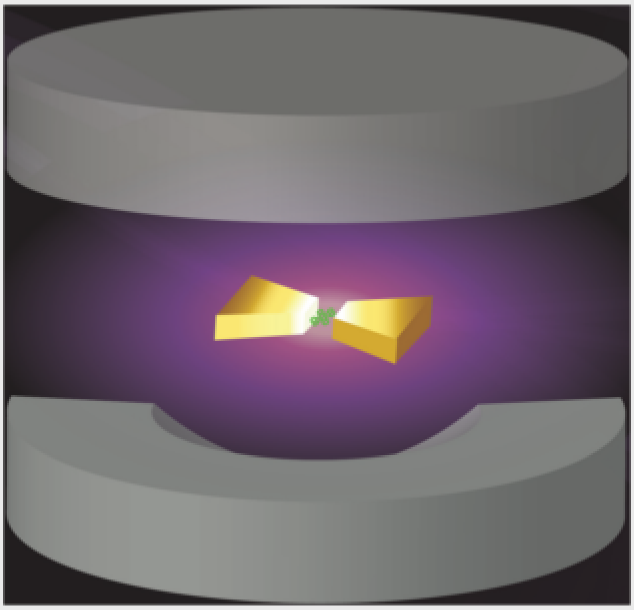
Enhancing Quantum Coherence of Organic Molecules with Nanophotonic Structures



Title: Enhancing Quantum Coherence of Organic Molecules with Nanophotonic Structures.

When: Monday, June 11, (2018), 12:00.

Place: Department of Theoretical Condensed Matter Physics, Faculty of Sciences, Module 5, Seminar Room (5th Floor).

Speaker: Diego Martín Cano, Nano-Optics Division, Max Planck Institute For The Science Of Light, Erlangen, Germany.

The optical coherence lies at the heart of quantum phenomena that arise from the interaction between light and matter. To maintain and control such coherence is crucial for the development of quantum optical technologies, since it is intrinsically involved in the generation of nonclassical features that allow surpassing the capabilities of classical systems. One of the experimental approaches to access this quantum coherence is to use the interaction of light with electronic transitions that are available in solid state emitters. However, the coherence of these transitions is commonly hindered by additional interactions arising from the materials that host the emitters.

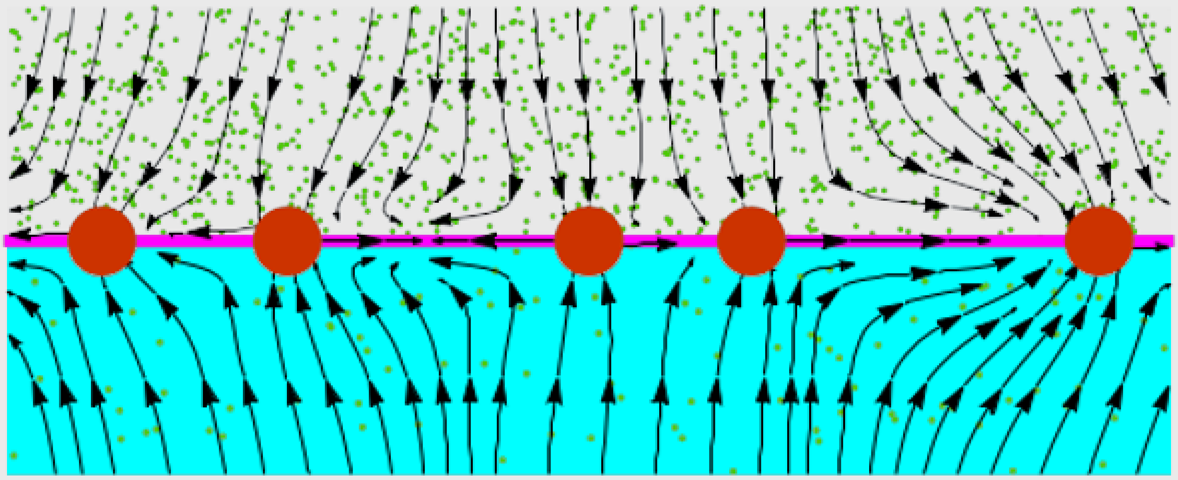
In this talk I will present some of our theoretical attempts to propose nanophotonic structures that ameliorate such loss of quantum coherence, with an emphasis on aromatic hydrocarbons in organic crystals [1,2], and to provide fundamental measures to test it [3,4]. These efforts include the exploration of nanostructures embedded in optical microcavities, which we show they provide access to stronger coherent interactions and suppression of emission quenching near metals [5].

References

H. Kelkar, D. Wang, D. Martín-Cano, B. Hoffmann, S. Christiansen, T. Utikal, S. Götzinger, V. Sandoghdar, Phys. Rev. App., 4, 054010 (2015).

D. Wang, H. Kelkar, D. Martin-Cano, T. Utikal, S. Götzinger, V. Sandoghdar, Phys. Rev. X, 7, 021014 (2017).
D. Martín-Cano, H.R. Haakh, K. Murr, M. Agio, Phys. Rev. Lett., 113, 263605 (2014).
H. Haakh, D. Martín-Cano, ACS Photon., 2, 1686 (2015).
B. Gurlek, V. Sandoghdar, D. Martín-Cano, ACS Photon., 5, 456 (2018).

Active Colloid at a Fluid Interface



Title: Active Colloid at a Fluid Interface.
When: Tuesday, June 05, (2018), 12:00.
Place: Department of Theoretical Condensed Matter Physics, Faculty of Sciences, Module 5, Seminar Room (5th Floor).
Speaker: Álvaro Domínguez, Atomic, Molecular and Nuclear Physics Department, Universidad de Sevilla, Spain.

The last years have witnessed the growing interest on active colloids, i.e., of colloids made of particles that exhibit chemical activity: this activity induces gradients in the ambient fluid and thus drives a self-induced colloidal dynamics. This kind of systems have attracted attention both as a paradigm of nonequilibrium physics and for its potential applications.
In this talk, I will present recent theoretical work focused on a monolayer of active colloid formed at a fluid interface. A new phenomenology arises which is exclusive to the combination “activity + interface”, because the interface is also responsive to chemical gradients: the spatial variations of the surface tension induce Marangoni flows

in the ambient fluids that manifest themselves as an effective interaction between the colloidal particles and between these and the interface. At the mean-field level, this interaction is analogous to two-dimensional Newtonian gravity. A particularly interesting result is the existence of “pseudoequilibrium” particle distributions in the monolayer describing the Marangoni-induced coexistence of thermodynamic phases. I will finally discuss the experimental evidence and the feasibility of observing the theoretical predictions.

References

H. Masoud and M. Shelley, Phys. Rev. Lett., 2014, 112, 128304.

A. Dominguez, P. Malgaretti, M. N. Popescu and S. Dietrich, Phys. Rev. Lett., 2016, 116, 078301.

A. Dominguez, P. Malgaretti, M. N. Popescu and S. Dietrich, Soft Matter, 2016, 12, 8398b, 8406.

A. Dominguez and M. N. Popescu, arXiv:1804.01451.

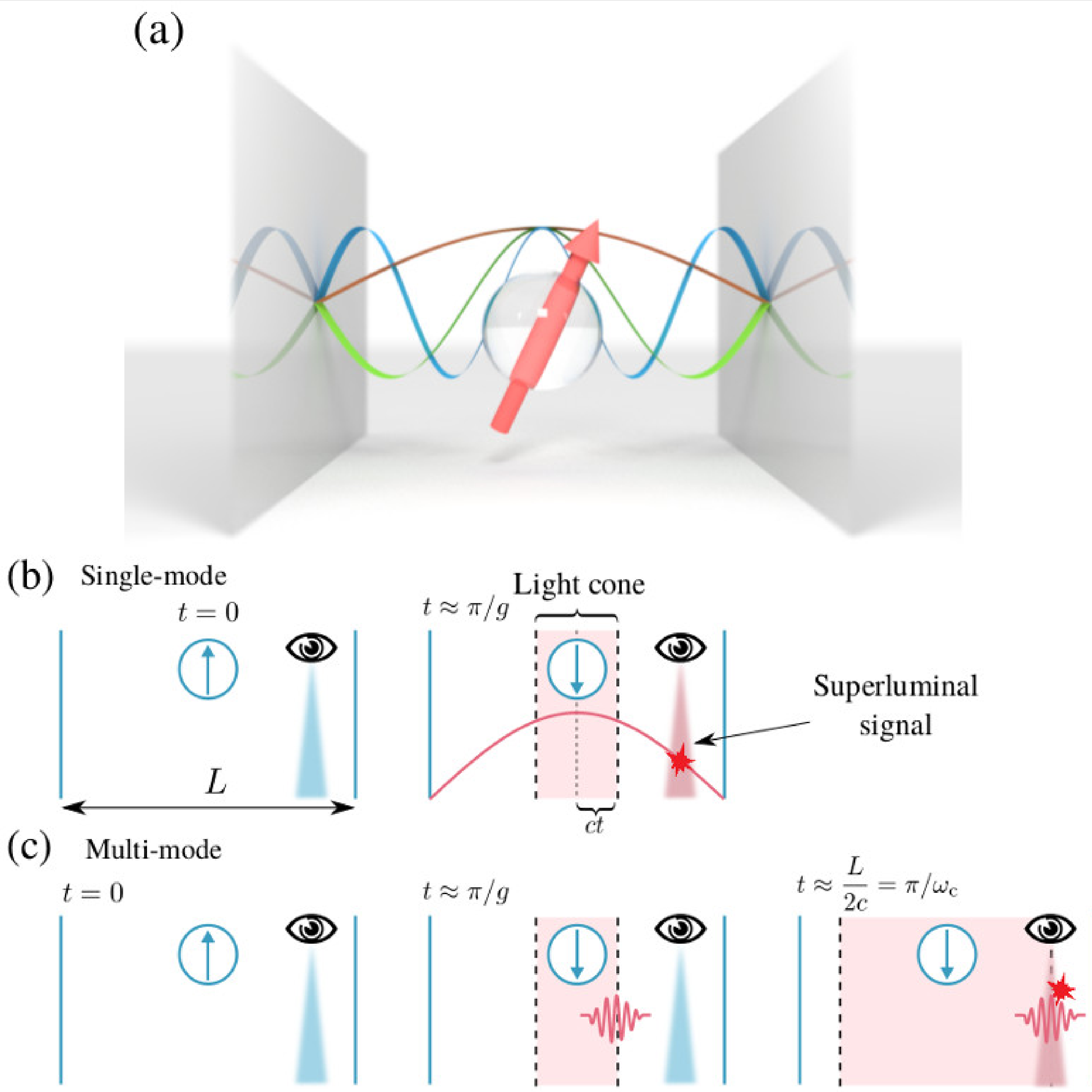
FET Open Project CATCH-U-DNA: Capturing non-Amplified Tumor Circulating DNA with Ultrasound Hydrodynamics

This multidisciplinary suggest replacing the labor-intensive, occasionally biased and costly PCR method currently used for the detection of genetic cancerigenous markers with a simple, non-PCR based DNA quantification method. The suggested system will exploit the ability of acoustic waves in the surface of quartz resonators to probe the hydrodynamic shape of surface-bound molecules, rather than its mass. The scientific challenge to be addressed is to push the limit of detection to the zM range obviating the need to use a polymerase for DNA amplification. The technological challenge is to fabricate ultra sensitive acoustic devices and capture with high efficiency very low numbers of DNA present in a complex medium on the device surface. These ambitious goals will be achieved by developing novel probes with liposomes and nanoparticles of tailor-made sizes and shapes for enhanced acoustic response; exploiting high frequency acoustic devices up to the GHz range; and, employing magnetic beads with microfluidics for specific target-capturing and enrichment. The proof-of-principle will be demonstrated during the detection of circulating-tumor DNA (ctDNA), currently an area perceived by cancer researchers as the "Holy Grail" of future cancer diagnosis, prognosis and treatment. We intend to validate our integrated acoustic platform towards the detection of common mutations occurring in colorectal and lung cancers, i.e., KRAS, EGFR and BRAF in serum. We anticipate that the "CATCH-U-DNA" concept will set the foundations for a simpler, more sensitive and affordable diagnostic method, from which patients in both the developed and developing countries will greatly benefit. The consortium involves 7 groups (FORTH (Crete), BGU (Israel), AWS (Valencia), UOC (Universitary Hospital at Crete), Curie Institute (Paris), JOBST (Friburg) and UAM (Madrid).

The UAM group leaded by the IFIMAC member Rafael Delgado-Buscalioni in the Department of Theoretical Condensed Matter Physics, is in charge of the theoretical description of the probe dissipation, using hydrodynamic simulations to propose new ways to improve the sensitivity by increasing the dissipation. The detection of extremely low concentrations of DNA using ultra-sensitive acoustic probes targets will push the detection limit down to the zM range without PCR, produce highly selective and specific isolation of ctDNA targets in serum with the fluidized bed technology towards the final target: Demonstrate the simultaneous detection of 48 colorectal and lung cancer mutations from ctDNA.

We congratulate Prof. Rafael Delgado-Buscalioni.

Resolution of Superluminal Signalling in Non-perturbative Cavity Quantum Electrodynamics



gnalling in the single-mode Rabi model. a) Schematic view of a qubit embedded in a perfect 1D cavity, together with the depiction of the three lowest cavity modes. When the qubit is only coupled to the fundamental mode, the system is described by the Rabi Hamiltonian. b) Violation of relativistic causality by the single-mode Rabi model in regimes where $g \approx \omega c$. An observer placed close to the cavity edge can retrieve information about the initial state of the TLS before light is able to reach its position. c) A multi-mode description is able to capture the spatio-temporal structure of the light field necessary to comply with causality.

Title: Resolution of Superluminal Signalling in Non-perturbative Cavity Quantum Electrodynamics.

When: Monday, May 21, (2018), 12:00.

Place: Department of Theoretical Condensed Matter Physics, Faculty of Sciences, Module 5, Seminar Room (5th Floor).

Speaker: Carlos Sánchez Muñoz, RIKEN Cluster for Pioneering Research, Wako-shi, Japan.

Recent technological developments have made it increasingly easy to access the nonperturbative regimes of cavity quantum electrodynamics known as ultrastrong or deep strong coupling, where the light–matter coupling becomes comparable to the bare modal frequencies [1].

In this talk, I will discuss the adequacy of the broadly used single-mode cavity approximation to describe such regimes. We have demonstrated that, in the non-perturbative light–matter coupling regimes, the single-mode models become unphysical, allowing for superluminal signalling [2]. Moreover, considering the specific example of the quantum Rabi model, we show that the multi-mode description of the electromagnetic field, necessary to account for light propagation at finite speed, yields physical observables that differ radically from their single-mode counterparts already for moderate values of the coupling. Our multimode analysis also reveals phenomena of fundamental interest on the dynamics of the intracavity electric field, where a free photonic wavefront and a bound state of virtual photons are shown to coexist.

References

Forn-Díaz, P., Lamata, L., Rico, E., Kono, J., & Solano, E. (2018). arXiv:1804.09275.

Sánchez Muñoz, C., Nori, F., and De Liberato, S., Nature Communications (2018) 9:1924.

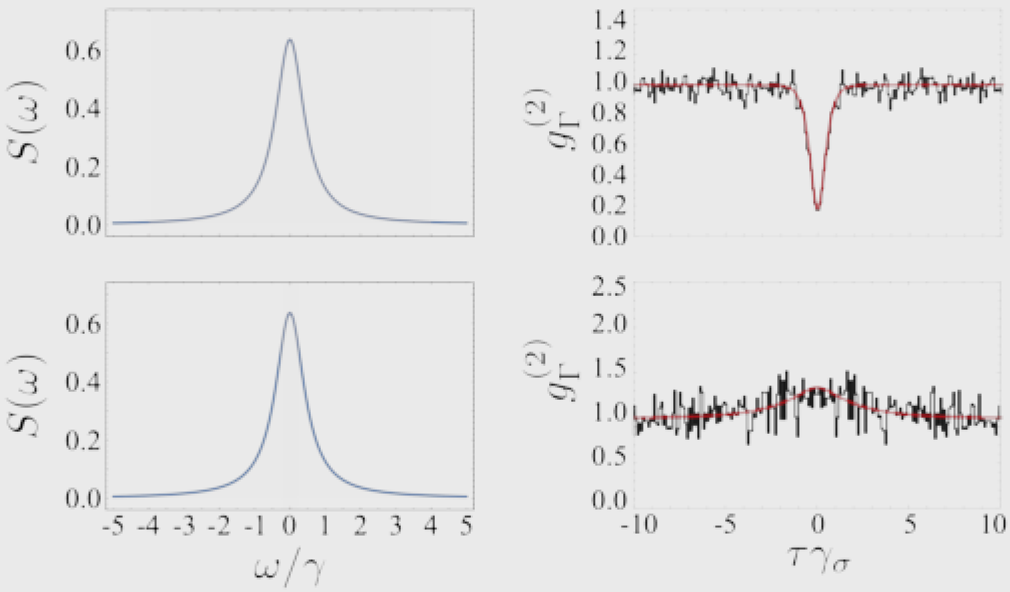
It is our great pleasure to announce the XXV International Summer School "Nicolás Cabrera". This series of summer schools, organized by the Instituto Nicolás Cabrera at the Universidad Autónoma de Madrid and financed by the Fundación BBVA, deals with current topics in Materials Science since 1994. Next year, it will focus on "Manipulating Light and Matter at the Nanoscale", and will be held from the 10th to the 14th of September 2018 in Miraflores de la Sierra, Spain (close to Madrid).

This international school aims to provide a broad introduction to current trends in light-matter interactions at the nanoscale to students and young postdocs. A list of confirmed keynote and invited speakers, as well as other details and information, can be found at INC Summer School 2018.

The School will consist of lectures, discussions, and poster sessions, and will last from the morning of Monday, Sep 10, until around noon on Friday, Sep 14. It will include a half-day excursion to a landmark and a traditional dinner in the vicinity of Madrid.

Note that registration is already open. The fee (400€) covers accommodation, meals, and coffee breaks, as well as the school trip and dinner. A limited number of scholarships to waive the registration fee will be available.
If you have any questions, please, do not hesitate to contact us at school@nicolascabrera.es.

Frequency-resolved Monte Carlo



Photon correlations of the light emitted by a two-level system change as the resolution in the energy of the photons is increased. The correlations obtained through our Monte Carlo technique (shown in black) match perfectly with the prediction from the theory frequency-resolved correlations (shown in red).

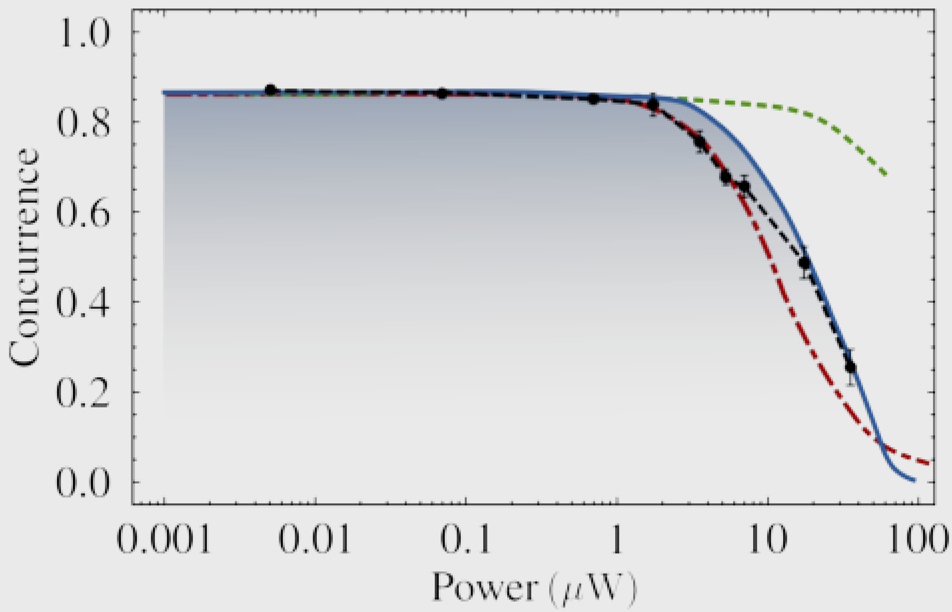
Article: published in Scientific Reports by Juan Camilo López Carreño, Elena del Valle, members of the Department of Theoretical Condensed Matter Physics.

The Monte Carlo method, devised by Ulam in the 1940s, relies on random sampling to estimate the value of variables in problems that are difficult to tackle analytically. In particular, the method has proven specially helpful to simulate stochastic problems, such as the trajectories of a random walker (which has application across all sciences) or the neutron diffusion.
In the late 80s and early 90s, Zoller, Marte & Walls and Dalibard, Castin & Molmer adapted the Monte Carlo method to the formalism of the quantum master equations, in which the stochastic processes, such as spontaneous emission, are described as Lindblad terms. In this paper [Sci. Rep. 8, 6975 (2018)], we extend the range of

applicability of the Monte Carlo method, by adapting it to the Cascaded formalism of Quantum Optics, which enables us to simulate the emission of photons of known energies.

We apply the technique to the photon emission from a two-level systems driven by either an incoherent or a coherent pump. Doing a statistical analysis of the photon-emission streams, we find a perfect agreement with the theory of frequency-resolved correlations, which confirms the correctness of our technique. In particular, using a coherent driving in the Mollow triplet regime, we demonstrate directly the manifestation of the so-called "leapfrog processes" whereby the two-photon emission rate is increased. [Full article]

First Observation of the Quantized Exciton-polariton Field and Effect of Interactions on a Single Polariton



Article: published in Science Advances by Juan Camilo López Carreño, Blanca Silva, Elena del Valle, members of the Department of Theoretical Condensed Matter Physics.

In 1982 Richard Feynmann envisioned the Quantum Computer, and although it has received the attention of two generations of Quantum Physicist around the world, its realization is still in a gestational stage. Many efforts have been devoted to demonstrate both the suitability and the miniaturization potential of diverse platforms to encode and manipulate Quantum Information. On these counts, photons would be the ideal carriers if it was not for their lack of interactions, without which the logical gates (the building blocks of a computer) cannot be implemented.

Creation of a quantum polariton.

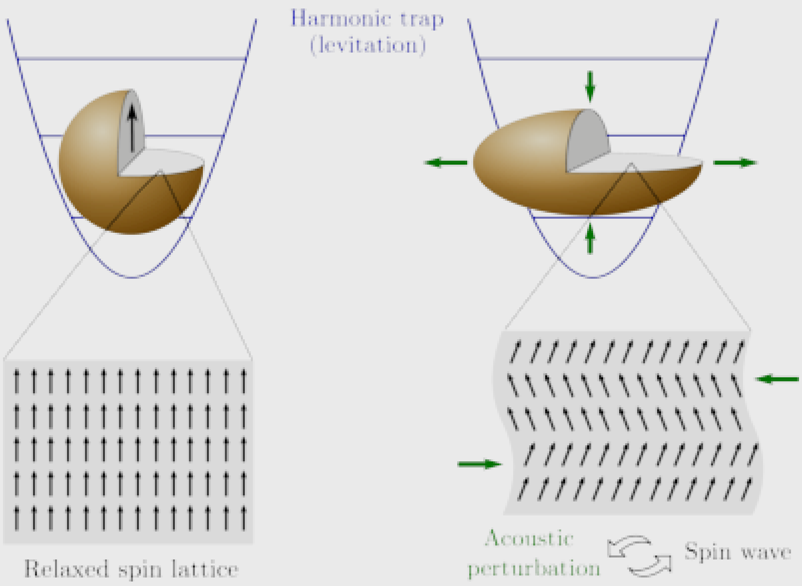
Exciton-polaritons, hybrid particles that arise from the strong coupling between a photon and an exciton (an electron-hole pair), are a natural substitute of photons, as they inherit an interactive character from the excitons while retaining the lightweight and coherence from the photons. In a recent paper [Sci. Adv. 4, eaao6814 (2018)], by exciting the field of exciton-polaritons (from here on simply “polaritons”) with one of the photons from a pair of polarization-entangled photons, we observed for the first time a genuine quantum state (i.e., one that cannot be described as a convex mixture of Gaussian states) of the polariton field. A measurement of the classical CHSH inequality between the light emitted by the polariton and the other photon from the entangled pair shows that the quantum correlations are maintained, even after one of the photons became a polariton. Furthermore, by letting the single polariton cohabit with a condensate of polaritons, we were able to alter the phase of the single-polariton, as observed through an apparent loss of entanglement. This shows that polaritons could be fully manipulated at the quantum level in the near future and become the qubits of a quantum computer. [Full article]

Physics Degree at UAM No. 1 - "El Mundo" Universtities Ranking 2018

The Autonomous University of Madrid appears as the first one in the ranking of universities conducted by the newspaper El Mundo to pursue the career of Physics.

The 18th edition of 50 CARRERAS gathers the 50 most popular grades among the students and the five best universities where to take them. The classification is the result of a detailed analysis of 25 criteria, the opinion of 2,000 professors and other external studies (international rankings, ANECA reports, etc.). [More info]

Theoretical Challenges in Levitated Nanomechanics: the case of magnon-phonon interaction



Title: Theoretical Challenges in Levitated Nanomechanics: the case of magnon-phonon interaction.
When: Thursday, May 10, (2018), 15:00.
Place: Department of Theoretical Condensed Matter Physics, Faculty of Sciences, Module 5, Seminar Room (5th Floor).
Speaker: Carlos Gonzalez-Ballestero, Institute for Quantum Optics and Quantum Information of the Austrian Academy of Sciences, & Institute for Theoretical Physics, University of Innsbruck, Austria.

Starting from the first studies on cavity optomechanics some decades ago, and reaching the present day with, for instance, the ultrasensitive motion detectors at LIGO, mechanical degrees of freedom have been integrated into many areas of quantum physics [1]. In nanomechanics, a particularly promising possibility is the stable levitation of nanoscale objects since, by eliminating the clamping losses, it allows for e.g. quantum state control at room temperature, or generating macroscopic quantum superpositions of the motional states [2, 3]. In the last few years, these potential applications have sparked significant experimental advances, e.g. the achievement of stable levitation in ultra-high vacuum, and the cooling of the motion close to the ground state [4, 5].

By establishing the field of levitated nanomechanics, the above experiments have opened up exciting new prospects. For instance, trapped systems are ideal nanolabs where one can study problems in e.g. condensed matter physics, optics, or magnetism in a practically lossless, extremely controllable scenario. Remarkably, along this line experiments lie well ahead of theory, since most of the conventionally used approximations are expected to break down at those extreme scales, possibly allowing for the emergence of new regimes. Thus, developing adequate theoretical models is key to understand the physics of these systems.

In this talk, I will address some of the fundamental open problems in levitated nanosystems and the methods we are employing to tackle them. As an example, I will focus on the magnon-phonon interaction in levitated nanomagnets. I will show how this interaction is not only stronger, but qualitatively different than in macroscopic samples, and briefly comment on the implications regarding nanomagnetometry, thermometry and quantum acoustodynamics.

References

M. Aspelmeyer, T. J. Kippenberg, and F. Marquardt, Rev. Mod. Phys. 86, 1391 (2014).

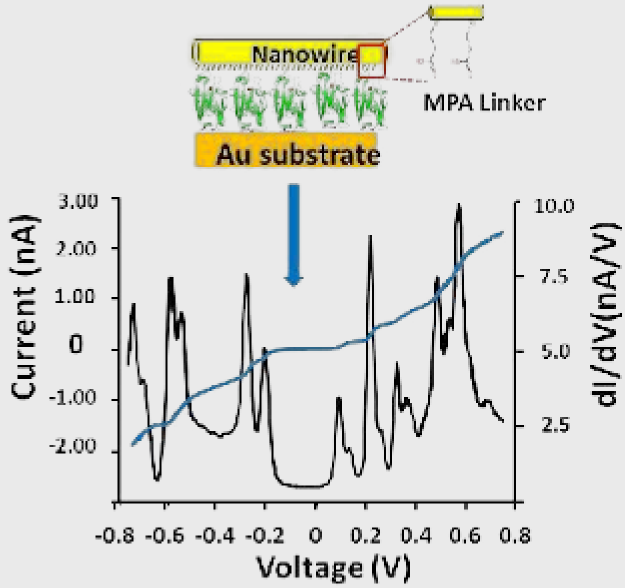
M. Bhattacharya, A. N. Vamivakas, and P. Barker, J. Opt. Soc. Am. B 34, LO1-LO2 (2017).

O. Romero-Isart, A. C. Pflanzer, F. Blaser, R. Kaltenbaek, N. Kiesel, M. Aspelmeyer, and J. I. Cirac, Phys. Rev. Lett. 107, 020405 (2011).

Vijay Jain, Jan Gieseler, Clemens Moritz, Christoph Dellago, Romain Quidant, and Lukas Novotny, Phys. Rev. Lett. 116, 243601 (2016).

J. Millen, P. Z. G. Fonseca, T. Mavrogordatos, T. S. Monteiro, and P. F. Barker, Phys. Rev. Lett. 114, 123602 (2015).

Resonant Tunneling in Protein-based Junctions



Resonant tunneling through an Azurin monolayer.

Article: published in PNAS by Juan Carlos Cuevas, IFIMAC researcher and member of the Department of Theoretical Condensed Matter Physics.

Proteins play a fundamental role in numerous biological energy conversion processes such as photosynthesis, respiration, and a wide variety of enzymatic reactions. In recent years, redox proteins containing transition metal ion centers have been integrated into solid-state electronic junctions. The goal is to shed new light on the electron transfer mechanisms in these biomolecules, but also to investigate the possibility of using proteins as active elements in novel, bio-inspired electronic devices. In this context, recent experiments have shown that the electron transport through proteins can be surprisingly efficient. However, the origin of this efficiency and, in general, the underlying transport mechanisms remain largely unknown.

New light on this fundamental problem has now been shed in a work published in the *Proceedings of the National Academy of Sciences of USA* (PNAS) by a collaboration between the group of David Cahen (Weizmann Institute of Science, Rehovot, Israel) and the IFIMAC researcher Juan Carlos Cuevas. In this work, these researchers report low-temperature (10 K) electron transport measurements via monolayer junction based on the blue copper protein Azurin that strongly suggest that quantum tunneling is the dominant charge transport mechanism. In particular, they show that weakening the protein-electrode coupling by introducing a spacer, one can switch the electron transport from off-resonant to resonant tunneling, which has never been reported before in protein-based junctions. Moreover, vibronic features of the Cu(II) coordination sphere were identified in the transport characteristics, which shows directly the active role of the metal ion in the resonant tunneling. These results illustrate how quantum mechanical effects may dominate electron transport via protein-based junctions, which is clearly at variance with the common wisdom in the field of protein electron transfer in biological settings. [Full article]