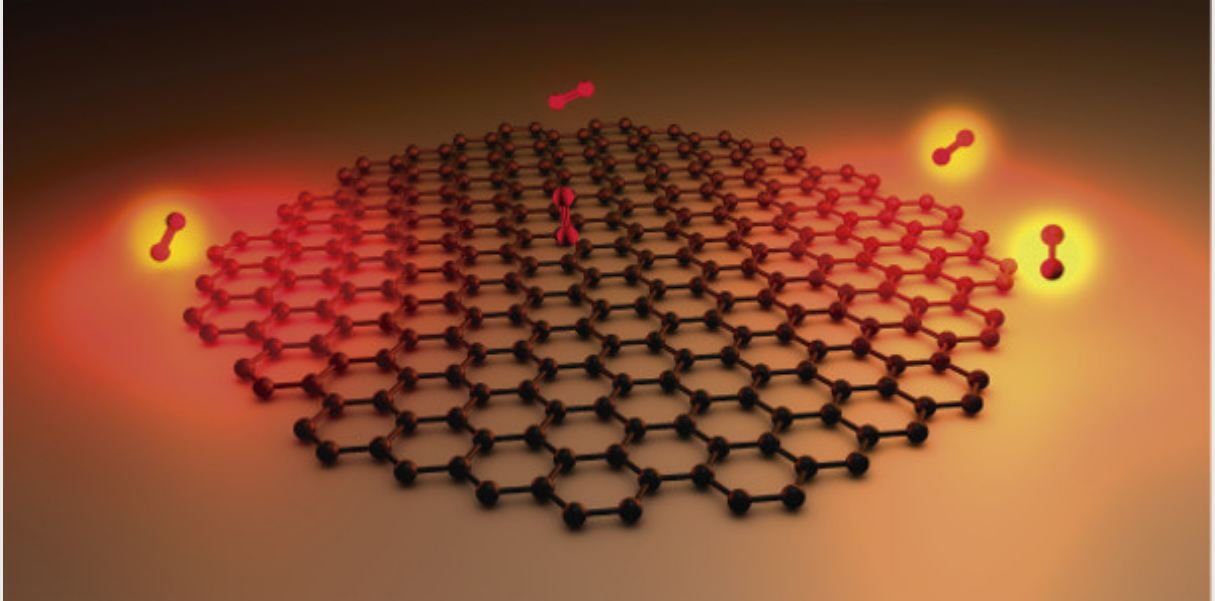


Metallic Nanostructures and Quantum Emitters



Title: Metallic Nanostructures and Quantum Emitters.

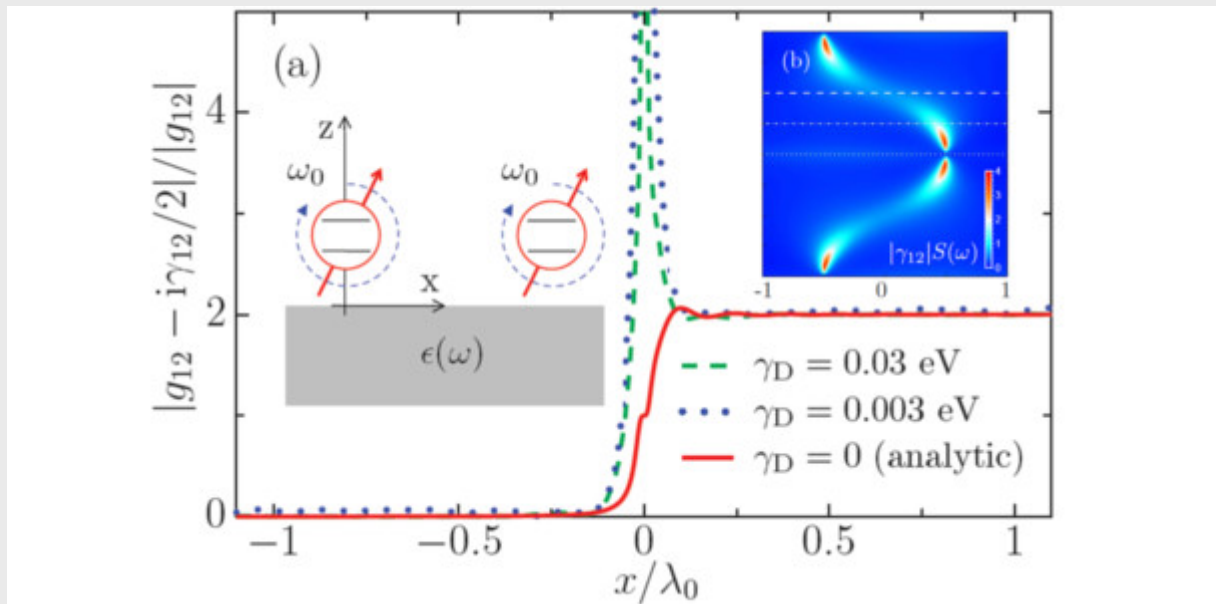
When: Wednesday, April 03, (2019), 12:00.

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

Speaker: Alejandro Manjavacas, University of New Mexico, USA.

The optical response of quantum emitters, such as atoms, molecules, or quantum dots, is strongly modified by their interaction with the near-field of metallic nanostructures that support plasmon resonances. In this talk, we will discuss recent results showing how different metallic nanostructures, ranging from 3D gold elements to 2D graphene systems, can enhance the rates of dipole-forbidden transitions. Furthermore, we will analyze the fundamental limits of the local density of photonic states, a magnitude that quantifies the interaction of a quantum emitter with the local electromagnetic field, through the study of a sum rule that establishes an upper bound to this quantity. Finally, if time permits, we will discuss the response of arrays with multi-particle unit cells using an analytical approach based on plasmon hybridization, which provides a simple and efficient way to design structures with engineered properties.

[Quasichiral Interactions between Quantum Emitters at the Nanoscale](#)

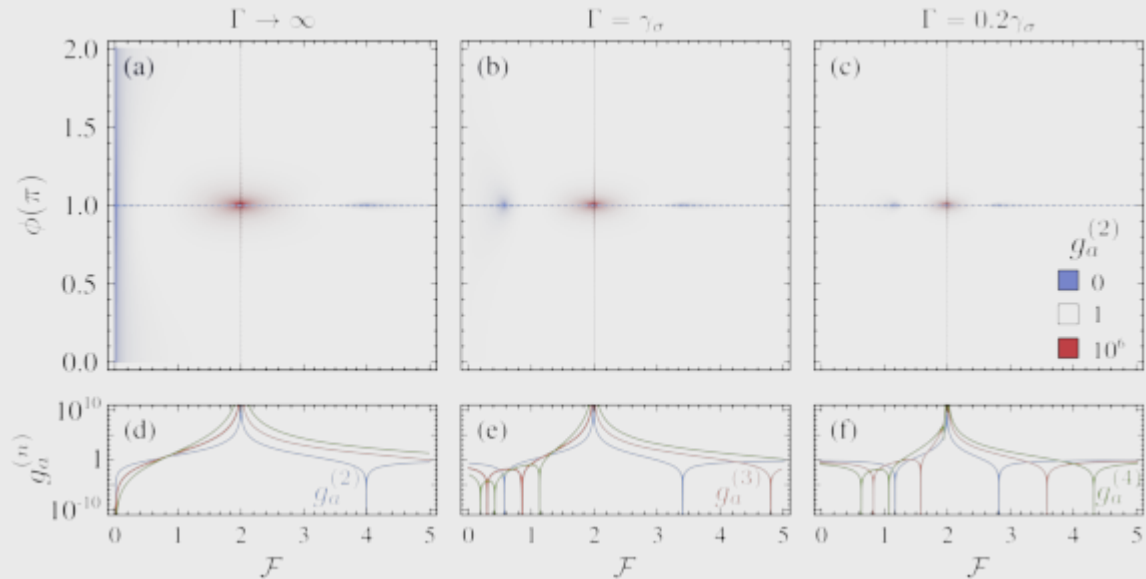


Article: published in [Physical Review Letters](#) by J. C. López Carreñ, Elena del Valle and Antonio I. Fernández Domínguez, [IFIMAC](#) researchers and members of the Department of Theoretical Condensed Matter Physics.

Chirality (or handedness) is an important concept across modern science. The word “chiral” was originally used to describe objects which were not identical to their mirror images, but now the term now encompasses asymmetries in many forms, including in chemical reactions and in sub-nuclear processes. The emerging field of chiral quantum optics is concerned with systems where forward and backward moving photons interact differently with a quantum emitter (such as atoms, molecules or quantum dots) The most extreme case of chirality is the unidirectional (or one-way) coupling between two quantum systems. Scientists are increasingly interested in exploiting chiral light-matter interactions in order to realize novel applications in the areas of quantum communication, information and computing.

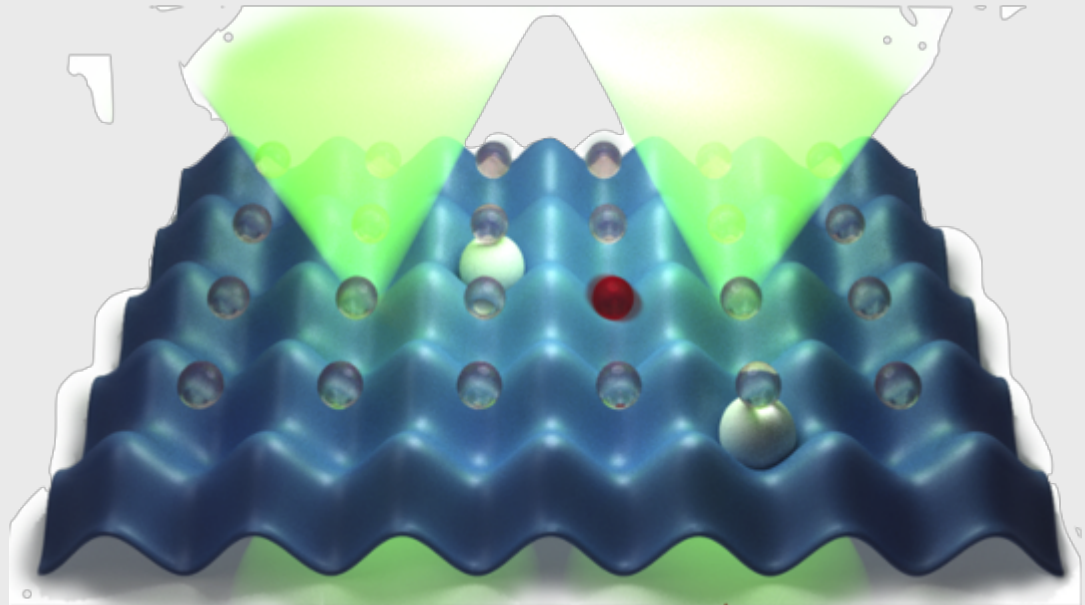
New insight into the area of chiral quantum optics has now been revealed in a work published in [Physical Review Letters](#) (PRL) by Elena del Valle, Antonio Fernández-Domínguez and co-workers. This work proposes a system consisting of two circularly-polarized quantum emitters held above a plasmonic surface as tunable setup in which one may explore chiral light-matter coupling at the nanoscale. Most excitingly, these researchers reveal a hitherto unknown regime, dubbed “quasichiral”, which is the stage for a number of remarkable quantum optical phenomena. In particular, the quasichiral regime gives rise to extremely sharp and intense spectral features (which may be important for sensing) and strong photon correlations, including strong photon antibunching (which appears in a remarkable butterfly structure in the two-photon spectra). The full article can be read here. [[Full article](#)]

Impact of Detuning and Dephasing on a Laser-corrected Subnatural-linewidth Single-photon Source



Article: published in [Journal of Physics B: Atomic, Molecular and Optical Physics](#) by J. C. López Carreño, E. Zubizarreta Casalengua and E. del Valle, members of the Department of Theoretical Condensed Matter Physics.

We discuss a scheme which makes interfere the emission from a qubit with a laser to produce single photons with subnatural linewidth (monochromatic), although having both properties seems to be in contradiction with the Heisenberg uncertainty principle. In this paper, we consider the effect of dephasing and of the detuning between the driving laser and/or the detector with the emitter. We find that our scheme brings such considerable improvement as compared to the standard schemes as to make it one of the best single-photon sources. While the scheme is particularly fragile to dephasing, its superiority holds even for subnatural-linewidth emission down to a third of the radiative lifetime. [[Full article](#)]



Title: Analog Quantum Chemistry Simulation with Ultra-cold Atoms.

When: Friday, November 30, (2018), 12:00.

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

Speaker: Alejandro Gonzalez Tudela, Institute of Fundamental Physics, CSIC, Madrid, Spain.

Solving quantum chemistry problems with a quantum computer is one of the most exciting applications of future quantum technologies. Current efforts are focused on finding an efficient algorithm that allow the efficient simulation of chemistry problems in a digital way. In this talk, I will present a complementary approach to the problem which consists in simulating quantum chemistry problems using ultra-cold atoms. I will first show how to simulate the different parts of the Hamiltonian, and then benchmark it with simple molecules.

References

Unconventional quantum optics in topological waveguide QED, Miguel Bello, Gloria Platero, Juan Ignacio Cirac, Alejandro González-Tudela, arXiv:1811.04390, (2018).

Title:
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September 27, (2018), 11:00.

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

Speaker: Peter Rabl, Vienna University of Technology, Austria.

In quantum optical systems the coupling between a single dipole and a single cavity mode is always much smaller than the absolute energy scales involved, which allows us to understand and model light-matter interactions in terms of well-defined atomic and photonic excitations. With recent advances in the field of circuit QED it is now possible to go beyond this well-established paradigm and enter a fully non-perturbative regime, where the coupling between a single artificial atom (e.g. a superconducting qubit) and a microwave photon exceeds the energy of the photon itself. Such conditions can be associated with an effective finestructure constant of order unity and in this talk I will give a brief introduction about the basic models and novel effects that govern the physics of light-matter interactions in this previously inaccessible regime.

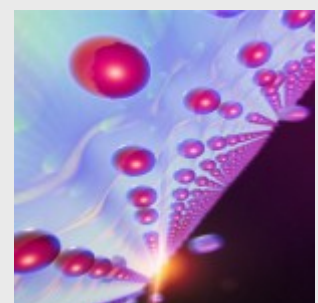
[Quantum Optics in Low Dimensions: From Fundamentals to Applications](#)

Title: Quantum Optics in Low Dimensions: From Fundamentals to Applications.

When: Wednesday, February 8, (2017), 12:00.

Place: Departamento de Física de la Materia Condensada, Facultad
Ciencias, Module 3, Seminar Room (5th Floor).

Speaker: Alejandro Gonzalez-Tudela, Max Planck Institute für



Quantenoptik, Germany.

Recent experimental developments in nanophotonics [1], circuit QED [2] and cold atoms [3] allow to engineer systems where quantum emitters couple to low dimensional photon-like reservoirs with non-trivial energy dispersions. Compared to three-dimensional and structureless baths, the interactions induced by such structured environments can be strongly enhanced and have long-range character. In this talk, I will show several phenomena that can emerge in these scenarios such as the existence of multi-photon bound states around single quantum emitters [4], the generation of tuneable long-range coherent interactions [5], or how one can boost the fidelities and efficiencies of non-classical states of light [6].

References

Nature 508, 241–244 (2014), Nature Communications 5, 3808 (2014), Rev. Mod. Phys. 87, 347 (2015).

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[More information on IFIMAC Website](#)

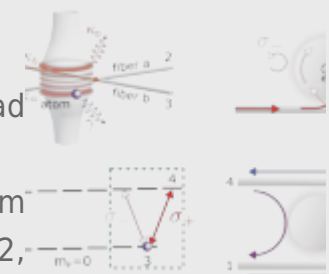
Chiral Quantum Optics

Title: Chiral Quantum Optics.

When: Friday, February 3, (2017), 12:00.

Place: Departamento de Física de la Materia Condensada, Facultad de Ciencias, Module 3, Seminar Room (5th Floor).

Speaker: Arno Rauschenbeutel, Vienna Center for Quantum Science and Technology, Atominstitut, TU Wien, Stadionallee 2, 1020 Wien, Austria.



Controlling the interaction of light and matter is the basis for diverse applications ranging from light technology to quantum information processing. Nowadays, many of these applications are based on nanophotonic structures. It turns out that the

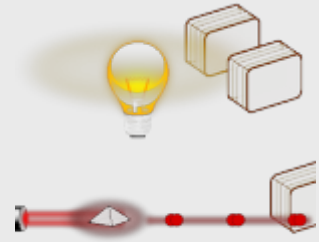
confinement of light in such nanostructures imposes an inherent link between its local polarization and its propagation direction, also referred to as spin-momentum locking of light [1]. Remarkably, this leads to chiral, i.e., propagation direction-dependent effects in the emission and absorption of light, and elementary processes of light-matter interaction are fundamentally altered. For example, when coupling plasmonic particles or atoms to evanescent fields, the intrinsic mirror symmetry of the particles' emission can be broken. In our group, we observed this effect in the interaction between single rubidium atoms and the evanescent part of a light field that is confined by continuous total internal reflection in a whispering-gallery-mode microresonator [2]. In the following, this allowed us to realize chiral nanophotonic interfaces in which the emission direction of light into the structure is controlled by the polarization of the excitation light [3] or by the internal quantum state of the emitter [4], respectively. Moreover, we employed this chiral interaction to demonstrate an integrated optical isolator [5] as well as an integrated optical circulator [6] which operate at the single-photon level and which exhibit low loss. The latter are the first two examples of a new class of nonreciprocal nanophotonic devices which exploit the chiral interaction between single quantum emitters and transversally confined photons.

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- C. Junge, D. O'Shea, J. Volz, and A. Rauschenbeutel, Strong coupling between single atoms and non-transversal photons, *Phys. Rev. Lett.* 110, 213604 (2013).
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[More information on IFIMAC Website](#)

Article: published in [Physical Review A](#) by J. C. López Carreño, C. Sánchez Muñoz, E. del Valle and F. P. Laussy, [Department of Theoretical Condensed Matter Physics](#) and IFIMAC researchers..



A theoretical analysis of the interaction between quantum light and matter shows that quantum light can offer advantages over its classical analog. Interactions between classical light and matter lie at the heart of a broad range of applications—think sunlight striking a solar panel or laser light scanning a barcode. But what happens when quantum light such as light made of “squeezed” or entangled photons interacts with matter? In two back-to-back papers, Fabrice Laussy from the [Autonomous University of Madrid](#), Spain, and colleagues now report a theoretical analysis of the interaction between quantum light and matter that, unlike most previous studies, doesn’t solely apply to specific types of quantum light. The researchers find that quantum light offers advantages over its classical counterpart for certain systems and applications. [\[Full article\]](#)

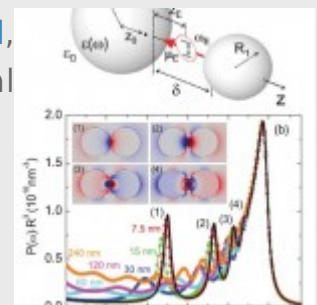
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Excitation with quantum light. I. Exciting a harmonic oscillator, J. C. López Carreño and F. P. Laussy, *Phys. Rev. A* 94, 063825, (2016). [\[URL\]](#)

Excitation with quantum light. II. Exciting a two-level system, J. C. López Carreño, C. Sánchez Muñoz, E. del Valle, and F. P. Laussy, *Phys. Rev. A* 94, 063826, (2016). [\[URL\]](#)

[Transformation Optics Approach to Plasmon-Exciton Strong Coupling in Nanocavities](#)

Article: published in [Physical Review Letters](#) by F. J. García-Vidal, and A. I. Fernández-Domínguez, [Department of Theoretical Condensed Matter Physics](#) and IFIMAC researchers.



We investigate the conditions yielding plasmon-exciton strong coupling at the

single emitter level in the gap between two metal nanoparticles. Inspired by transformation optics ideas, a quasianalytical approach is developed that makes possible a thorough exploration of this hybrid system incorporating the full richness of its plasmonic spectrum. This allows us to reveal that by placing the emitter away from the cavity center, its coupling to multipolar dark modes of both even and odd parity increases remarkably. This way, reversible dynamics in the population of the quantum emitter takes place in feasible implementations of this archetypal nanocavity. [Full article]

Classical and Quantum Electrodynamics of Light-matter Coupling

Title: Classical and Quantum Electrodynamics of Light-matter Coupling

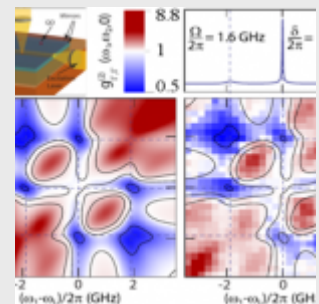
Project acronym: CLAQUE

Funding Agency: Spanish Ministry of Science and Innovation - MINECO.

Principal Investigators: [Antonio I. Fernández-Domínguez](#), [Elena del Valle](#) and [Fabrice Pierre Laussy](#).

Duration: January 2016 - December 2018.

Description:



The enormous growth experienced in the last century by all the areas of optics was driven by the fact that the energy of visible photons lies within the energy range of electronic and vibrational transitions in matter. This makes photons ideal probes of nature at all length scales: from intergalactic to interatomic distances. This pervasive character of light made it a key instrument for many of the most influential scientific and technological advances of the last few decades. The ubiquitous nature of photons inherently implies a serious fundamental drawback: they interact very weakly with matter at a microscopic level. CLAQUE brings together complementary expertises in the physics of light to break new grounds in the interaction of light with matter in two emerging areas—nano and quantum optics—that overcome this apparently inviolable constrain.

Nano-optics deals with the concentration of light beyond the diffraction limit of classical optics, which has made possible enhancing light-matter interactions at the nanoscale.

We will exploit the peculiar fashion in which electromagnetic fields transform under geometric operations to shape them at deeply sub-wavelength spatial regimes. This will be done through metal systems supporting surface plasmons, with the purpose of designing open photonic nanocavities. We will enter in the spatial range where electronic quantum effects become relevant, which will require the modelling of metal permittivities beyond the classical macroscopic picture. We will also explore sub-wavelength photon manipulation at lower frequencies. Specifically, we will investigate strongly hybridized localized surface infrared modes to increase the radiative heat transfer efficiency between objects separated by near-field distances. We will consider both naturally occurring resonances, such as phonon or plasmon polaritons, and geometrically induced spoof plasmon modes. Finally, we will focus on electron-photon coupling phenomena which are inherently beyond the realm of classical electromagnetics. Particularly, we will study plasmon-assisted hot electron generation in metallic nanogaps through the combination of density functional and electromagnetics theory.

Quantum optics focuses on the striking physical phenomena that occur when involving only a few and strongly correlated photons, situations inaccessible until very recently from both theoretical and experimental perspectives. Specifically, we account self-consistently for the dynamical correlations from quantum emitters, thanks to our recently introduced formalism of frequency-resolved N-photon correlations that retain the energy information as well as the conventional temporal one. This allows us to tune the type and optimize the strength of photon correlations by spectral filtering of the source in a process akin to distillation. We then use such dynamical correlations as a quantum input to excite or probe various targets. On the one hand, we analyse new paradigms of optical spectroscopy based on quantum light excitation. On the other hand, by studying dynamical quantum interferences, we propose applications for quantum information processing by dynamically feeding circuits with source outbeating classical lasers.

Strong from these complementary approaches, the project culminates with the proposal and design of new quantum nano-optical devices that emerge from the synergic combination of both scientific areas, namely, hybrid nano-antennas for tailored quantum light sources.
