

## Non-perturbative Cavity QED

Title:

Non-

pert

urba

tive

Cavi

ty

QED.

Whe

n:

Thur

sday



,  
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.

---

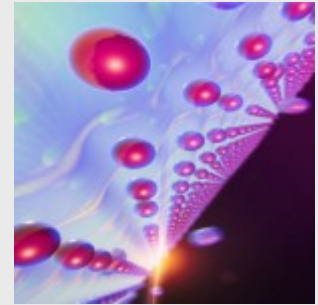
[Quantum Optics in Low Dimensions: From Fundamentals to Applications](#)

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.



**R**ecent 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).

Nature Physics 13 (1), 48-52 (2017).

Nature Physics 8, 267–276 (2012), Physical Rev Lett. 101 (26), 260404 (2010).

Physical Review X 6 (2), 021027 (2016).

Nature Photonics 9 (5), 320-325 (2015), PNAS, 201603777 (2016).

Physical Review Letters 115 (16), 163603 (2015), New Journal of Physics 18 (4), 043041, arXiv:1603.01243, (2016).

[More information on IFIMAC Website](#)

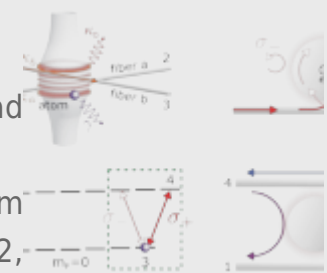
## Chiral Quantum Optics

Title: Chiral Quantum Optics.

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

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

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



# C

ontrolling 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.

## References

K. Y. Bliokh, F. J. Rodríguez-Fortuño, F. Nori, and A. V. Zayats, Spin-orbit interactions of light, *Nat. Photon.* 9, 796 (2015).

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).

J. Petersen, J. Volz, and A. Rauschenbeutel, Chiral nanophotonic waveguide interface based on spin-orbit coupling of light, *Science* 346, 67 (2014).

R. Mitsch, C. Sayrin, B. Albrecht, P. Schneeweiss, and A. Rauschenbeutel, Quantum state-controlled directional spontaneous emission of photons into a nanophotonic waveguide, *Nature Commun.* 5, 5713 (2014).

C. Sayrin, C. Junge, R. Mitsch, B. Albrecht, D. O'Shea, P. Schneeweiss, J. Volz, and A. Rauschenbeutel, Nanophotonic Optical Isolator Controlled by the Internal State of Cold Atoms, *Phys. Rev. X* 5, 041036 (2015).

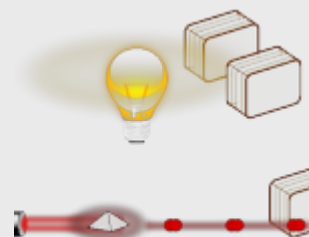
M. Scheucher, A. Hilico, E. Will, J. Volz, and A. Rauschenbeutel, Quantum optical circulator controlled by a single chirally coupled atom, *Science*, 354, 1577 (2016).

[More information on IFIMAC Website](#)

---

## When Quantum Light Meets Matter

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. [\[Full article\]](#)

### References

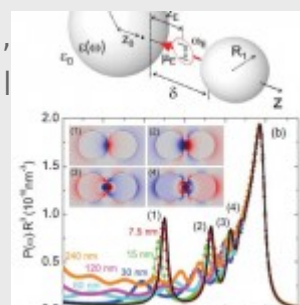
Excitation with quantum light. I. Exciting a harmonic oscillator, J. C. López Carreño and F. P. Laussy, *Phys. Rev. A* 94, 063825, (2016). [\[URL\]](#)

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.



# W

e 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

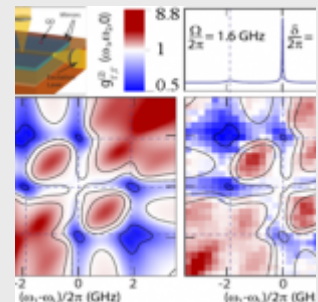
Project acronym: CLAQUE

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:



# T

he 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

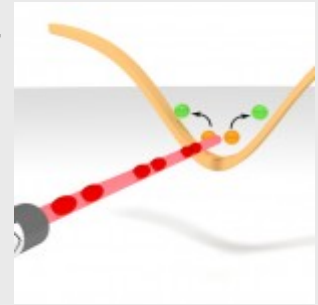
emerging areas—nano and quantum optics—that overcome this apparently inviolable constrain.

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.

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



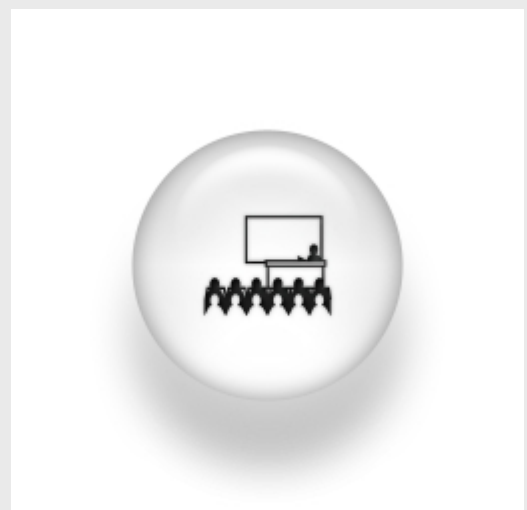
**F**or about five decades, research in quantum optics has been focused on photon correlations of systems excited by a laser. In this Letter, we propose a change in this paradigm, namely, we replace the laser with the emission of a quantum system. This emission has special features that a laser doesn't have, e.g., it is highly correlated. Turning to quantum light thus allows us to explore new regimes of excitation. As an illustration of this approach, we consider the quantum light emitted by a two-level system, impinging on a passive cavity or one embedding quantum wells. The later case gives rise to so-called polaritons, particles of light and matter, with wondrous properties including high temperature BEC, superfluidity and a full gamut of nonlinear optical effects. Specifically, we show how quantum light, thanks to its reduced fluctuation and statistical properties, allows us to measure exactly the polariton interaction, even when it is weak as compared to dissipation. This technique that we refer to as "Mollow spectroscopy", after the Mollow lineshape of resonance fluorescence used as the quantum source, should be of general interest for a wide range of optical targets and open new grounds in the nascent field of quantum spectroscopy. [\[Full article\]](#)

---

## Quantum Optics as Tools to Probe the Spacetime Structure

Tuesday, 10th November 2011. 15:00-16:00

*Eduardo Martín Martínez*



## ABSTRACT:

Relativistic quantum information theory uses well-known tools coming from quantum information and quantum optics to study quantum effects provoked by gravity and to learn information about the spacetime. One can take advantage of our knowledge about quantum optics and quantum information theory to analyse from a new perspective the effects produced by the gravitational interaction. I will present some results and new ideas in this topic: two experimental proposals for the detection of the Unruh and Hawking effects and a quantum simulation of general relativistic settings.

---