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# Light emission from current-driven plasmonic nanocavities

Andrés Bejarano[1,3] , Rémi Avriller[3], Fabio Pistolesi[3] and Thomas Frederiksen[1,2]

*[1]Donostia International Physics Center (DIPC), E-20018 Donostia-San Sebastián, Spain*
*[2] Ikerbasque, Basque Foundation for Science, E-48013 Bilbao, Spain*
*3 Univ. Bordeaux, CNRS, LOMA, UMR 5798, F-33405 Talence, France*

The study of electromagnetic cavities is interesting because it allows, for example, to explore light-matter interactions. If an atom/molecule is placed inside such a cavity and an electronic current is driven through the nanoscale object, it is possible to obtain light emission. Interesting photon statistics may appear, for instance so-called anti-bunching, where two individual photons are unlikely to be emitted close in time. Such single-photon sources with well-controlled photon statistics are highly desirable with applications in the field of quantum cryptography.

Junctions formed with scanning tunneling microscopes (STM) may act as plasmonic cavities and have been shown to emit single photons. However, a complete theoretical picture of single-molecule light emission is challenging and has become an active area of research in the last couple of years. Here we report on our theoretical efforts to understand the interaction between the plasmonic cavity and molecular emitter.

email: *andres.bejarano@dipc.org*

# Creating and measuring sub-wavelength volumes using quantitative absorption imaging of optically dense ensembles

Simon Bernon

*Institut d'Optique, Graduate School Photonics, Numerics and Nano-sciences Laboratory - University of Bordeaux*

Quantum gas microscopes have become a major element for quantum simulations using ultra-cold atoms in optical lattices. They are for example used to observe long-range order such as anti-ferromagnetic correlations in far field optical lattices using density and spin resolved microscopy. Decreasing the period of such lattice offer interesting perspective to increase atom-atom interaction energies and engineer atom-light coupling that our group tackles via the hybridization of cold atoms and nano-structured surfaces. In this poster, we will present how such type of sub-wavelength lattice potentials can be generated by trapping atoms in proximity (tens to hundreds of nanometers) of a nano-structured surface. At such atom to surface distance, the attractive Casimir-Polder force can be compensated by a doubly dressed state trapping method that I will discuss. Such method additionally offers solutions to overcome the diffraction limit of conventional imaging that become critical for sub-wavelength lattices. In this work, I will present the experimental characterization of a sub-wavelength resolution absorption imaging applicable to quantum gas detection. This method requires a quantitative determination of the atom number of dense clouds which has been characterized in this work and demonstrate that the scattering cross section reduces linearly with the optical density. Modelling the propagation of light in dense cloud we show that this reduction can be attributed to re-scattering of the incoherent part of the resonant fluorescence spectrum. The poster will additionally present an update on our recent work on the spectroscopy of Acetylene in sealed hollow core fibers.

# Spin chains in a superconductor towards topological superconductivity

**Cristian Mier[1], Nicolas Lorente[1,2] and Deung-Jang, Choi[1,2,3]**

[1]*Centro de Fisica de Materiales, CFM/MPC (CSIC-UPV/EHU), Paseo Manuel de Lardizabal 5, 20018 Donostia-San Sebastian*

[2]*Donostia International Physics Center (DIPC), Paseo Manuel de Lardizabal 4, 20018 Donostia-San Sebastian*

[3]*Ikerbasque, Basque Foundation for Science, 48013 Bilbao, Spain*

The search for Majorana bound states (MBS) in solid-state platforms has motivated an increasing number experiments, in particular, the realization of spin chains using STM in a superconducting surface is of special interest due to the high degree of precision that this technique allows. We use Green's function formalism to simulate a 2D superconductor with a chain of magnetic atoms on its surface. The calculations obtained with this method show a great agreement with experimental results on atomic Cr chains on the $\beta$-$Bi_2Pd$ supercoductor [1,2]. We study two types of magnetic chains with different distance between the atomic impurities and orientation with respect to the surface. The calculations allows us to distinguish different topological character between the two, showing that one of the studied chains is in a non-trivial topological phase, and thus, we expect the emergence of MBS in this system [1,3].

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# High-fidelity ground state preparation for quantum simulations of the two dimensional Z2 lattice gauge theory

Jesús Cobos Jiménez

A new variational method for the ground state preparation of the Z2 gauge theory in digital quantum computers is proposed. It is based on the well known QAOA, but the variational ansatz includes a non-unitary operation acting over the reference state. The introduction of this non-unitary operation induces an improvement on the ground state approximation, specially around the phase transition, which is the regime in which the traditional QAOA becomes less powerful. It is shown that the implementation of the non-unitary operation on a quantum computer does not introduce a disproportionate computational overhead, thus enabling this method to be used in future quantum simulations of the Z2 gauge theory.

# Universal Features of Entanglement Entropy in the Honeycomb Hubbard Model

Jonathan D'Emidio, Roman Orús, Nicolas Laflorencie, Fernando de Juan

The entanglement entropy is a unique probe to access universal features of strongly interacting fermionic systems. Sign-problem-free unbiased quantum Monte Carlo algorithms have been proposed to compute the Rényi entanglement entropies, but these methods have not yet reached the precision required to detect subtle subleading universal terms. We leverage recent conceptual advancements in computing Rényi entanglement entropies in bosonic systems in order to devise an improved method in auxiliary-field determinental quantum Monte Carlo simulations for fermions, based on the free fermion decomposition of the reduced density matrix. Remarkably, this approach is insensitive to the rare events that cause a breakdown of traditional implementations, even though it preserves the same computational efficiency and requires no extra numerical stabilization. This enables us for the first time to resolve universal subleading logarithmic terms of the Rényi entanglement entropy in a 2D model of interacting fermions, which we demonstrate by studying the half-filled honeycomb Hubbard model at $T = 0$. Here we are able to detect Goldstone modes of the antiferromagnetic Mott insulating phase at large $U$, as well as the universal corner contribution at the Gross-Neveu-Yukawa critical point.

# Decoding nanoscale NMR signals with deep learning

Estibaliz Garrote

Quantum sensors exploit quantum properties of matter to measure and detect target signals with high accuracy, sensitivity and resolution. Nitrogen-vacancy (NV) center based sensors make use of the properties that emerge when a nitrogen atom is integrated into a carbon diamond crystal structure. In particular NVs can capture the magnetic response of small sample sizes, otherwise inaccessible with standard NMR devices. This paves the way to detection of single molecules, such as proteins or other molecules of biological interest. The present work proposes an approach to decipher the information contained in the signal received from NV based quantum sensors. It includes a theoretical formulation of the signal under different set ups and activation sequences. In particular, a deep learning based processing algorithm is trained with the generated theoretical data and an artificial intelligence (AI) model will be applied to process experimental data processing.

# Prohibited optical trapping regimes unlocked by focused OAM beams

**I. Gomez-Viloria**[1,*], Á. Nodar[1], M. Molezuelas-Ferreras[1], J. J. M. Varga[1], and G. Molina-Terriza[1,2,3]

[1] *Centro de Física de Materiales, Paseo Manuel de Lardizabal 5, 20018 Donostia-San Sebastian, Spain*
[2] *Donostia International Physics Center, Paseo de Manuel Lardizabal 4, 20018 Donostia-San Sebastián, Spain*
[3] *IKERBASQUE, Basque Foundation for Science, Maria Diaz de Haro 3, 48013 Bilbao, Spain*

*e-mail: iker_gomez@hotmail.com

In this work, we present a novel optical trapping method which extends the known trapping regime provided by common focused Gaussian beams, making use of Laguerre-Gaussian (LG) beams with orbital angular momentum (OAM). This new possibility of trapping was discovered thanks to an efficient and general optical forces calculation procedure, formed by a fully analytical formula [1] in terms of well-defined helicity multipoles [2] and which enables displaced laser beams calculations [3,4]. The fields interacting with the sphere were derived by the application of Generalized Lorentz-Mie theory, which gives an analytical description of our system and extends the validity of the calculated expressions to particles of any size. Apart from that, the chosen decomposition provides us some computational tools for increasing the efficiency of the calculated simulations, which at the end of the day, has been crucial in the discovering of the mentioned behaviour. The most remarkable computational technique is the use of "master displacement matrices", which basically multiply chains of these pre-calculated matrices in order to represent any arbitrary displacement of the incident field.

One of our proposals was obtained by the calculation of the stability maps for the Z axis (beam propagation direction) shown in figures 1 and 2. Here is possible to recognize the new zones in the trapping regime unlocked by the use of LG beams with OAM. The totality of the results was fulfilled with stability maps for the X/Y axes, which just confirmed the desired trapping regime.

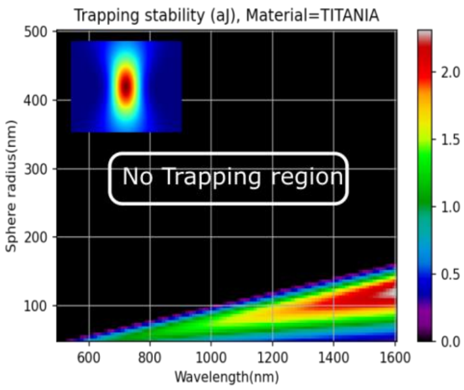


Figure 1: Trapping stability measured as the trapping potential height (aJ). The map has been created for a water suspended Titania ($TiO_2$) sphere, trapped by Gaussian beam focused with an objective lens of NA=1.20.

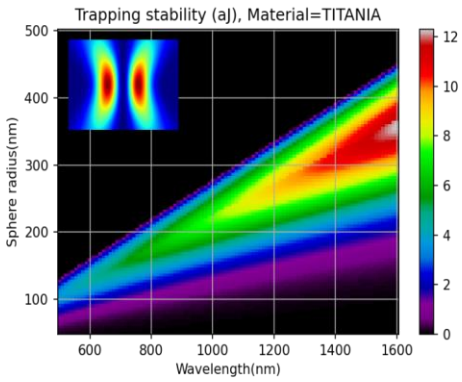


Figure 2: Trapping stability measured as the trapping potential height (aJ). The map has been created for a water suspended Titania ($TiO_2$) sphere, trapped by LG OAM beam focused with an objective lens of NA=1.20.

On the other hand, due to the well-defined helicity multipole decomposition, our formula naturally distinguish which force terms corresponds to each helicity contained in the incident light beam. In addition, although for the case with spherical particles the calculations are the simplest, it also enables to implement particles with different shapes. This study gives a very useful tool for exploring the relation between optical forces and the angular momentum of light.

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# Quasiparticle density of states and triplet correlations in superconductor/ferromagnetic-insulator structures across a sharp domain wall

Alberto Hijano Mendizabal

*Materials Physics Center, University of the Basque Country*

A ferromagnetic insulator (FI) in contact with a superconductor (S) is known to induce a spin splitting of the BCS density of states at the FI/S interface. This spin splitting causes the Cooper pairs to reduce their singlet-state correlations and acquire odd-in-frequency triplet correlations. We consider a diffusive FI/S bilayer with a sharp magnetic domain wall in the FI and study the local quasiparticle density of states and triplet superconducting correlations. For an arbitrary angle between the magnetizations and the strength of the exchange field, we numerically solve the problem of a sharp domain wall. We finally propose two different setups based on FI/S/F stacks, where F is a ferromagnetic layer, to filter out singlet pairs and detect the presence of triplet correlations via tunneling differential conductance measurements.

# Topological Lifshitz transitions, orbital currents, and interactions in low-dimensional Fermi gases in synthetic gauge fields

ChenHow Huang

Low-dimensional systems of interacting fermions in a synthetic gauge field have been experimentally realized using two-component ultracold Fermi gases in optical lattices. Using a two-leg ladder model that is relevant to these experiments, we have studied the signatures of topological Lifshitz transitions and the effects of the inter-species interaction $U$ on the gauge-invariant orbital current in the regime of large intra-leg hopping $\Omega$. Focusing on non-insulating regimes, we have carried out numerically exact density-matrix renormalization-group (DMRG) calculations to compute the orbital current at fixed particle number as a function of the interaction strength and the synthetic gauge flux per plaquette. Signatures of topological Lifshitz transitions where the number of Fermi points changes are found to persist even in the presence of very strong repulsive interactions. This numerical observation suggests that the orbital current can be computed from an appropriately renormalized mean-field band structure, which is also described here. Quantitative agreement between the mean-field and the DMRG results in the intermediate interaction regime where $U \lesssim \Omega$ is demonstrated. We also have observed that interactions can change the sign of the current susceptibility at zero field and induce Lifshitz transitions between two metallic phases, which is also captured by the mean-field theory. Correlation effects beyond mean-field theory in the oscillations of the local inter-leg current are also reported. We argue that the observed robustness against interactions makes the orbital current a good indicator of the topological Lifshitz transitions.

# Tunable Dirac points in a two-dimensional non-symmorphic wallpaper group lattice

Miguel Ángel Jiménez Herrera

We investigate the spectral properties of a two-dimensional electronic lattice belonging to a non-symmorphic wallpaper group. Specifically, we look at the herringbone lattice, characterised by two sets of glide symmetries applied in two orthogonal directions. We describe the system using a nearest-neighbour tight-binding model containing horizontal and vertical hopping terms. We find two non-equivalent Dirac cones inside the first Brillouin zone along a high-symmetry path. Among other features, these Dirac cones can be tuned via different perturbations applied to the Hamiltonian. These perturbations break the symmetries of the lattice: we begin by placing different onsite potentials in the lattice sites. We observe the annihilation of Dirac cones into semi-Dirac cones and nodal lines along high-symmetry paths. Finally, we perturb the system by applying a dimerization of the hopping terms. We report a flow of Dirac cones inside the first Brillouin zone describing quasi-hyperbolic curves. We present, as well, a possible implementation in terms of CO atoms placed on the top of a Cu(111) surface.

# Superconducting gap engineering

**Divya Jyoti[1,2], Cristian Mier[1], Deung-Jang, Choi[1,2,3] and Nicolas Lorente[1,2]**

[1]*Centro de Fisica de Materiales, CFM/MPC (CSIC-UPV/EHU), Paseo Manuel de Lardizabal 5, 20018 Donostia-San Sebastian*

[2]*Donostia International Physics Center (DIPC), Paseo Manuel de Lardizabal 4, 20018 Donostia-San Sebastian*

[3]*Ikerbasque, Basque Foundation for Science, 48013 Bilbao, Spain*

Superconducting behavior is strongly affected when a single impurity or chains of magnetic atoms are placed on a superconducting surface. The superconducting gap ($\Delta$) is modified on each atomic site throughout the lattice structure in the presence of the magnetic impurities. Here, we will present the results for the observation in one dimension. We use an analogy between Bogoliubov-de-Gennes (BdG) set of equations and Abrikosov-Gorkov theory in a lattice model giving rise to equations of motion for the Green's functions. This allows us to express the effect of the magnetic impurity via a self-energy that contains scattering off the impurity via its potential part (non-magnetic) and its exchange part (magnetic). From our work, we can envisage to craft superconducting and non-superconducting patterns on a material by creating structures of magnetic impurities on top of the superconductor. This will create materials that can be spatially modified, leading to an engineering of the superconducting gap.

# Many-molecule collective effects in Surface-Enhanced Raman Scattering described within a molecular optomechanics framework

A. Juan-Delgado †1, Y. Zhang [2], R. Esteban [1,3] and J. Aizpurua [1,3]
† adrian.juan@ehu.eus
[1] Materials Physics Center, CSIC-UPV/EHU, Donostia-San Sebastián (Spain)
[2] Henan Key Laboratory of Diamond Optoelectronic Materials and Devices, Zhengzhou University (China)
[3] Donostia International Physics Center DIPC, Donostia-San Sebastián (Spain)

Surface-Enhanced Raman Scattering (SERS) is a spectroscopic technique that provides information of the vibrational modes of a molecule. In SERS, the photons interchange energy with molecular vibrations, and the resulting inelastic scattering of photons is enhanced by the plasmonic resonance of a nearby metallic nanoparticle. Significantly, in many experimental situations a large number of molecules are located close to the metallic nanoparticle, but the molecules are assumed not to interact with each other in the standard description of SERS based on classical electrodynamics [1]. Thus, within this approach, many-molecule collective effects are not captured and the Raman signal scales linearly with the number of molecules.

We analyze these collective effects by using a cavity quantum electrodynamics (c-QED) framework based on standard optomechanics that has been developed in the last years to describe a wide variety of phenomena in SERS [2-4], such as nonlinearities [5, 6] and photon correlations [7]. Within this framework, we include the molecule-molecule interactions and observe that the emergence of collective effects occurs for sufficiently large illumination intensity. For laser intensities that increase the vibrational population beyond its thermal contribution, Raman signal scales quadratically with the number of molecules, in a phenomenon similar to superradiance. For stronger laser intensities, the collective interaction facilitates the appearance of other optomechanical effects, such as modifications of the vibrational linewidths and frequencies and a strong non-linear behavior with increasing laser intensity (divergence or saturation of the vibrational population, depending of the system). These results thus stress the importance of considering the interaction between molecules in SERS under strong laser illumination.

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# Computational Quantum Chemical Approaches in Computer-Aided Drug Design Workflow of Novel 3H-Thiazolo[4,5-b]pyridine-2-ones and Thiazolo[4,3-b]quinazolin

Olena Klenina

The 4-thiazolidone core was recognized as a biophoric structural pattern. Consequently, the combination of 4-thiazolidone template with pyridine moiety can be considered as a promising approach in drug-like molecules design with 4-thiazolidone as a precursor for the synthesis of some polyfunctionally substituted fused derivatives for which we might expect a wide spectrum of bioresponses.

The combination of two heterocyclic systems (thiazolidine and quinozoline rings) which are of the high priority in modern medicinal chemistry can be considered as the systematic approach for molecular rational design of drug candidates. Thiazolo[4,3-b]quinozolines are relatively unexplored with regard to their preparation synthetic protocols and biological actions.

# Field-free anomalous junction and superconducting diode effect in spin split superconductor/topological insulator junctions

Tim Kokkeler

We study the transport properties of a diffusive Josephson junction between two spin-split superconductors made of superconductor-ferromagnetic insulator bilayers (FIS) on top of a 3D topological insulator (TI). We derive the corresponding Usadel equation describing the quasiclassical Green's functions in these systems and first solve analytically in the weak-proximity case. We demonstrate the appearance of an anomalous phase in the absence of an external magnetic field. We also explore non-reciprocal electronic transport. Specifically, we calculate the junction's diode efficiency $\eta$ by solving the Usadel equation. We discuss how the diode efficiency depends on the different parameters, finding an interesting non-monotonic behavior of $\eta$ with the temperature.

# Proposal for an Andreev Spin Qubit with local exchange fields

Yao Lu

We propose to realize an Andreev spin qubit in a superconducting junction with exchange fields from a ferromagnetic insulator. The localized Andreev bound states with energies far below the superconducting gap are split to spin 1/2 states, and hence they can serve as a qubit called Andreev spin qubit. We show that this Andreev spin qubit features spin-dependent inductance, enabling the readout of the spin states. Furthermore, we demonstrate the existence of at least two sweet spots, at which the spin-to-phase coupling is switched off, which is important for quantum computing. We also discuss different systems that host the Andreev spin qubit, focusing primarily on nanowire-Al/EuS devices.

# Optical levitation of a sphere in vacuum for high sensitivity rotation sensing.

Miriam Martínez Flórez[1,*], Iker Gomez Viloria[1], Martin Molezuelas-Ferreras[1], J.J. Miguel Varga[1], Gabriel Molina-Terriza[1,2,3,**]

[1]Centro de Física de Materiales MPC-CSIC, UPV/EHU, Paseo Manuel de Lardizabal 5, 20018, Donostia - San Sebastián, Spain.
[2]Donostia International Physics Center, Paseo Manuel de Lardizabal 4, 20018, Donostia - San Sebastián, Spain.
[4]IKERBASQUE, Basque Foundation for Science, María Díaz de Haro 3, 48013, Bilbao, Spain.

*e-mail: miriammflorez@gmail.com - **e-mail: gabriel.molina@ehu.eus

Optical levitation has proven to be a very versatile tool for a wide branch of applications such as control of the rotational motion [1], testing quantum mechanics [2] or developing highly sensitive sensors [3]. This method allows to reduce the influence of the medium on the particle.

In this work, we present the current advances in the design and building of a single beam trap in the gravitational direction for levitating a micron-sized silica particle. The aim of the experiment is to rotate the levitated particle using the polarization of the trapping beam, and use the system to implement a high sensitivity rotation sensor.

For this purpose, the trapping takes place in a vacuum chamber that will enable to decouple the particle from most sources of thermal noise when going to high vacuum. The usual loading method for trapping nano-sized particles is to nebulize them close to the focus. However, for bigger particles this method is not valid anymore due to the size of the mesh, thus a different way of loading the particle is being reviewed. For example, the use of a piezo-electric and a coverslip to load the particle in the trap.

Besides, once the particle is trapped, a circular polarization of the beam will be used to transfer orbital angular momentum from the beam to the particle and induce in the latter a rotation. The main goal is to use the scattering spectra of the particle when it is rotating at high speed to implement a high sensitivity rotation sensor.

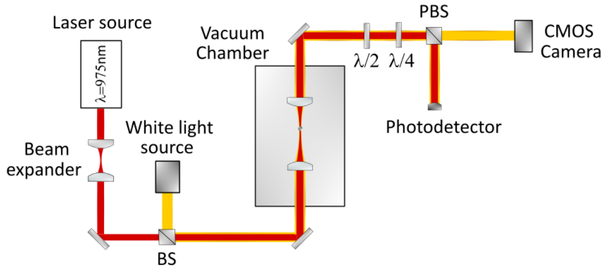


Figure 1. Experimental setup for trapping micron-sized particles in the gravitational direction.

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# Using highly focused light with helicity to characterize small particles

Martín Molezuelas-Ferreras[1], Álvaro Nodar[1], María Barra-Burillo[2], Jon Lasa-Alonso[1], J. J. Miguel Varga[1], Rubén Esteban[1,2], Javier Aizpurua[1,3], Luis Hueso[2], and Gabriel Molina-Terriza[1,2,3]

[1] Centro de Física de Materiales, Paseo Manuel de Lardizabal 5, 20018 Donostia-San Sebastian, Spain
[2] CIC nanoGUNE, Tolosa Hiribidea 76, 20018 Donostia-San Sebastián, Spain
[3] Donostia International Physics Center, Paseo de Manuel Lardizabal 4, 20018 Donostia-San Sebastián, Spain
[4] IKERBASQUE, Basque Foundation for Science, Maria Diazde Haro 3, 48013 Bilbao, Spain

Contact: mmolezuelas@gmail.com, alvaro_nodar001@ehu.eus, gabriel.molina.terriza@gmail.com

The angular momentum and helicity of light can be used to obtain information of a nanostructure [1,2]. In this experimental work we analyse the light scattered by TiO2 spherical microparticles when they are illuminated by a beam that has a well-defined total angular momentum and helicity, the latter defined as the spin projected in the direction of propagation. We focus specifically on the fields that are scattered in the backwards-direction, and we find clear oscillations in the spectrum of the backscattered field that can be used to obtain information about the size and refractive index of the microparticles.

We use Mie's theory [3] to analyse the experimental spectra and find a good agreement between theory and experiments. Our theory indicates that the oscillations are due to an interference between the different resonant modes of the microparticle. We find that the spectral oscillations are strongly shifted as the angular momentum of the incident beam is changed. Additionally, we derive an analytical method that indicates that the spectral oscillations are very sensitive to the product of the refractive index and the radius of the particle. Using this expression we extract the size and refractive index of several particles with great precision. We demonstrate that this method can also be useful to track changes in the microparticle, by analysing the behavior of these spectra at different pressures (ambient pressure and low vacuum, 1e-5 mbar). We find a shift in the spectrum that suggests slight changes on the particle's size with a precision of a few nanometers. This work thus presents a novel scattering-based method to characterize micro and nanoparticles of different materials.

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# Metrology-assisted entanglement distribution in noisy quantum networks

Simon Morelli

Entanglement shared between multiple users, for instance within a quantum network, is a crucial resource that allows one to overcome the restrictions of local operations and classical communication and thereby to implement classically impossible tasks. In this work we propose a novel strategy for the distribution of high-dimensional multipartite entanglement within noisy quantum networks with subsequent probabilistic state conversion. For certain types of noise the conversion can be carried out without the exact knowledge of the noise, which opens the possibility to use unsuccessfully converted copies for the estimation of the channel. Without sacrificing potentially good copies for this task, this protocol thus gains an advantage over comparable strategies in terms of the obtained number of copies close to the desired target state. Although this idea generalizes to various more complex situations, we focus on the realistic scenario, where only finitely many copies are distributed and where the parties are not required to process multiple copies simultaneously. We show the potential of the proposed strategy in a concrete example, where we consider the distribution of generic GHZ-type states in a network in the presence of local dephasing noise.

# Synthetic Weyl semimetal and quantum anomalous Hall state in a one-dimensional system of trilayer photonic grating

D.-H.-Minh Nguyen[a*], Xuan Dung Nguyen[b] , Hai-Son Nguyen[c,d], Dario Bercioux[a,e]

a. Donostia International Physics Center, 20018 Donostia-San Sebastian, Spain
b. Brown Theoretical Physics Center and Department of Physics, Brown University, 182 Hope Street, Providence, Rhode Island 02912, USA
c. Univ Lyon, ECL, INSA Lyon, CNRS, UCBL, CPE Lyon, INL, UMR5270, 69130 Ecully, France
d. Institut Universitaire de France (IUF)
e. IKERBASQUE, Basque Foundation for Science, Euskadi Plaza, 5, 48009 Bilbao, Spain
* minh.nguyen@dipc.org

We study the spectral properties of a one-dimensional (1D) trilayer photonic grating in a 3D hybrid momentum space with the interlayer shifts playing the role of two synthetic momenta besides the genuine one of our 1D system. As the synthetic momenta are even under the time-reversal operation, this family of 1D lattice can host states that are often realized in systems with time-reversal symmetry broken. We find that highly tunable Weyl semimetal, nodal line semimetal, and quantum anomalous Hall state can be realized in our trilayer system. The results show that multilayer photonic grating is not only a promising platform for studying higher-dimensional topological physics but also a simple one to observe phenomena that are hard to examine in solids.

# Photon correlations in the ultrastrong coupling regime of cavity-QED

Á. Nodar[1,*], R. Esteban[1], U. Muniain[2], M. J. Steel[1,2,3], J. Aizpurua[1,2], and M. K. Schmidt[1,2,3]

*Email: alvaro_nodar001@ehu.eus. T: +34 943 01 8828
[1] Centro de Física de Materiales CFM (CSIC-UPV/EHU), Paseo Manuel de Lardizabal, 5, 20018, Donostia, Spain
[2] Donostia International Physics Center DIPC, Paseo Manuel de Lardizabal, 4, 20018, Donostia, Spain
[3] Macquarie University Research Centre for Quantum Engineering (MQCEQ), MQ Photonics Research Centre, Department of Physics and Astronomy, Macquarie University, NSW 2109, Sydney, Australia

We study the correlations of the photons emitted by a two-level system (TLS) coupled to an optical (plasmonic) nanocavity (figure 1a). This system is widely used in quantum optics, but its description within cavity quantum electrodynamics (cavity-QED) is based on several approximations. One of these approximations is the Rotating Wave Approximation (RWA), which results in the Jaynes-Cummings Hamiltonian. However, it is known that this approximation does not work for extremely large coupling strengths, i.e. in the so-called Ultra Strong Coupling (USC) regime [1-2].

We use two different cavity-QED descriptions to model the cavity-TLS interaction : i) the approximated Jaynes-Cummings model and ii) the more rigurous gauge-fixed (GF) Rabi model [3-5]. The later has been recently developed to describe more accurately the TLS-cavity interaction, particularly in the ultra-strong coupling regime. We focus in the two-photon correlations $g^{(2)}(\tau = 0)$ of the emitted light, which contains information not present in the scattered intensity, and consider incoherent illlumination of the TLS.

Figure 1b shows $g^{(2)}(\tau = 0)$ obtained from the Jaynes-Cummings (red dashed line) and from the GF Rabi (blue solid line) models for different normalized coupling strengths $\eta = g/\omega_0$ (where $\omega_0$ is the resonant frequency of both the cavity and of the TLS). We vary the coupling strength from the weak ($\eta \lesssim 10^{-2}$) to the USC ($\eta \geq 0.1$) regime. The intensity correlations show anti-correlation ($g^{(2)}(0) < 1$) within the Jaynes-Cummings model for all considered coupling strengths. For small and moderate values of $\eta$, this behavior coincides with the result of the more accurate GF Rabi model. However, the GF Rabi model indicates that the photons emission gets strongly bunched in the USC regime ($g^{(2)}(0) > 1$), in strong contrast with the expectation from the Jaynes-Cummings model.

We explain the origin of the strongly bunched correlations of the emitted light by exploring the excitation and emission pathways in the cavity-TLS system, and show that the correlation function can be a more sensitive indicator of the breakdown of the RWA than the more commonly measured one-photon spectra.

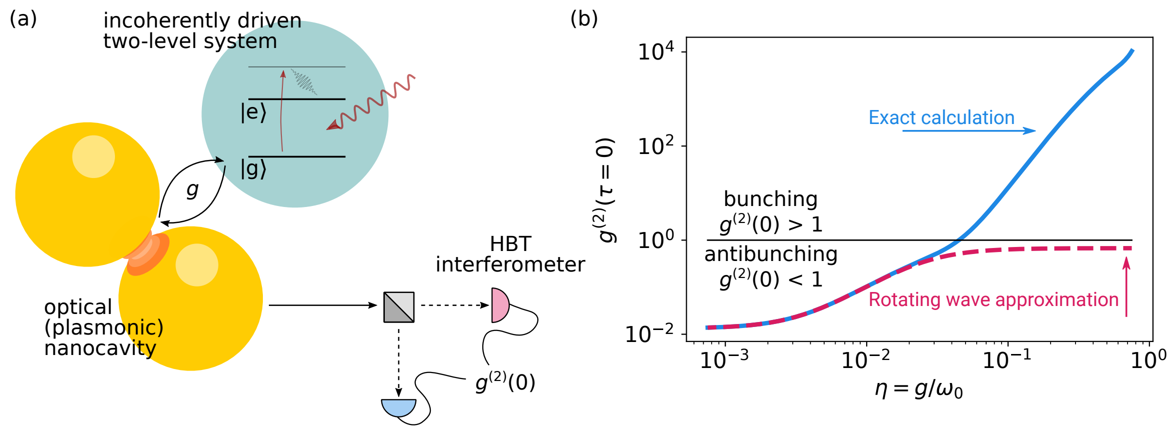


Figure 1: (a) Scheme of the system studied. An incoherently driven TLS interacts with an optical (plasmonic) nanocavity. The correlations of the photons emitted by the cavity are analyzed using a Hanbury Brown and Twiss (HBT) interferometer. (b) Intensity correlations ($g^{(2)}$) of this syste as a function of the normalized coupling strength ($g/\omega_0$, with $\omega_0 = 1$ eV the natural frequency of the TLS and of the cavity). The dashed red and solid blue lines correspond to the Jaynes-Cummings and the gauge-fixed (GF) Rabi calculations, respectively. The solid black line corresponds to $g^{(2)} = 1$ and separates the regions where bunching ($g^{(2)} > 1$) and antibunching ($g^{(2)} < 1$) are found. For these calculations, the TLS is pumped incoherently with a rate $P = 1$ meV, and the losses of the cavity and of the TLS are $\kappa = 50$ meV and $\gamma = 0.1$ meV, respectively.

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# Magnetic impurities in non-conventional superconductors

Jon Ortuzar, Stefano Trivino, and Katernia Vaxevani

Magnetic impurities interacting with superconductors build up subgap states named Yu-Shiba Rusinov (YSR). We use a low temperature STM to resolve them in tunneling spectra and interprete their origin by comparing with model theory simulations. In this poster we survey recent works of our group regarding atomic and molecular magnetic species on non-conventional superconductors such as proximitized gold films and the bimetallic superconductors Bi2Pd.

# Efficient quadrature microwave antenna for electron spin control on Nitrogen Vacancy centers in diamond

[1]Koen Custers, [2]Ruben Pellicer-Guridi, [2]Joseba Solozabal-Aldalur, [3]Alexey Brodoline, [4,5,6]Jorge Casanova, [1,7]Margarethus M. Paulides, [1,2,6]Gabriel Molina-Terriza

[1]Electromagnetics for Care & Cure Research Lab, Department of Electrical Engineering, Eindhoven University of Technology, Eindhoven, The Netherlands. [2]Centro de Física de Materiales, Donostia-San Sebastián, Spain. [3]Donostia International Physics Center, Donostia-San Sebastián, Spain. [4]Department of Physical Chemistry, University of the Basque Country UPV/EHU,Bilbao, Spain. [5]EHU Quantum Center, University of the Basque Country UPV/EHU, Leioa, Spain. [6]IKERBASQUE, Basque Foundation for Science, Bilbao, Spain. [7]Department of Radiotherapy, Erasmus University Medical Center Cancer Institute, Rotterdam, The Netherlands;

Nitrogen Vacancy (NV) centers in diamond are promising candidates for quantum technologies at room temperature, such as Quantum bits, magnetic field sensors, single molecule Nuclear Magnetic Resonance (NMR) imaging. Here, we present a novel microwave (MW) antenna design capable of generating a strong circularly polarized magnetic field that is homogeneous over a large volume. This kind of design is crucial for boosting the precision of spin control towards high performance NV based devices, as it will allow the accurate control of a large number of NVs at the same time, which increases the signal to noise ratio (SNR) of the measurements.

After initialization of the electron spin through pulsed green light, a MW field tuned to the right frequency offer the means to coherently manipulate the spin state. The design of this antenna has been optimized in order to achieve a large oscillating magnetic field. It has been proven that this configuration better preserves the spin coherence allowing for a larger fidelity in the control of the operations on the electronic spin.

This antenna has other interesting features due to its ability to generate a circularly polarized MW field, such as determining the direction of the external magnetic field. Most existing designs offer poor field homogeneity and only a few circularly polarized coils have been reported. However, most of the latter have a narrow and fixed frequency bandwidth, offer a limited optical access, are expensive to manufacture, or are poorly documented, which prevent reproducing them.[1,2] We present an antenna design that overcomes the above limitations.

Methods: Electro magnetics simulation software (CST) was used to design the antenna consisting of two independently-driven ports for generating a circularly or linearly polarized field on demand. The antenna can host two standard commercially available diamond dimensions (2x2x0.5 mm & 3x3x0.5 mm), and is manufactured with standard double sided PCB materials (FR4 of thickness 1.6 mm). Tailored to be resonant at 2.87 GHz by default, the antenna can easily be tuned to lower frequencies through additional capacitors. The antenna was built (Fig. 1A) and a Vector Network Analyzer was used to assess resonant frequency and power delivery efficiency. In addition, a magnetometry experiment with a bulk NV diamond was performed to corroborate the MW field generation.

Results: The antenna generates a magnetic field of 34 A/m when feeding 1 W of input power at a single port (Fig. 1B). The homogeneity is within 5 %, 2%, 1% and 0.1% in a radius of 1000, 260, 140 and 10 µm respectively. The reflected power was around -30 dB in simulations and measurement, but the resonant frequency is 2.87 GHz in the simulations and 2.85 GHz in the built antenna. The magnetometry experiment shown in Fig. 1C shows the fluorescence dip at ~10 gauss, which is in good agreement with the field measured with a commercial Gaussmeter. The longer dip on the left corresponds to the $m_S = 0 \Leftrightarrow -1$ electron spin transition and the shallower dip on the right corresponds to the $m_S = 0 \Leftrightarrow 1$ transition. The hyperfine coupling between electron and nuclear ($^{14}N$) spins can also be inferred from the three dents within this second dip.

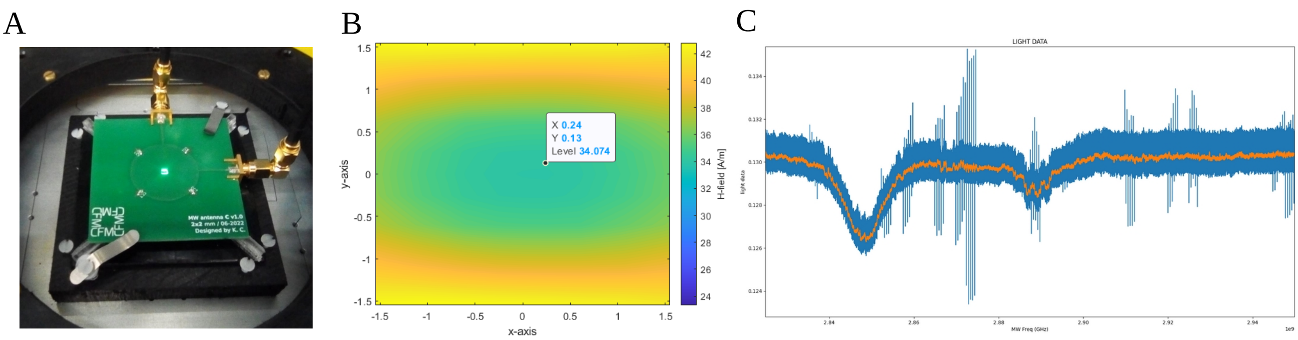


*Fig. 1 showing some results of the designed microwave antenna. A) A picture of one of the built MW antennas during an experiment being driven in quadrature. B) A simulation cross-section of the MW field strength along the central plane of the antenna. C) Plot of a magnetometry measurements showing two dips indicating the spin transitions between the $m_S = 0$ and the corresponding -1 and 1 populations.*

Discussion and conclusion: The measurements are in good agreement with the simulations. The largest discrepancy is on the resonant frequency, which is ~200 MHz lower in the constructed antenna. Nonetheless, the measured power loss on the ports is less than 2%, as simulated, which suggests that this difference in resonant frequency has a negligible effect on antenna efficiency. The different depths of the dips achieved for the MW frequencies corresponding to the spin transition $m_S = 0 \Leftrightarrow -1$ and $m_S = 0 \Leftrightarrow 1$ confirm that the antenna is indeed generating circularly polarized field. The direction of this polarization can be selected swapping the order of the cables driving the ports. The proposed design features better performance trade-offs compared to previous works as it enables tuning to a wide range of frequencies and generates a large and homogeneous circularly polarized MW field. The flat geometry of the antenna enable wide optical access, as required for high sensitivity experiments. Importantly, the antenna is inexpensive, easy to build, and robust to manufacturing imperfections. These properties make this antenna a versatile piece of instrumentation for a wide range of high-end NV based quantum technologies.

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# From Short-Range to Mean-Field Models in Quantum Lattices.

Kauê Rodrigues Alves

The Kac limit is a way of obtaining the thermodynamic behavior of mean-field models as the limiting case of a system subject only to short-range interactions. We prove new results for fermionic systems on a lattice, stating that the convergence holds not only for the thermodynamic pressure but also for equilibrium states (i.e., for all correlation functions). When both an attractive and a repulsive Kac interaction are present, we also show that the pressure of the system and the corresponding correlation functions do not necessarily converge to those of the conventional mean-field model, and can possibly lead to very unconventional (infinite volume) mean-field models.

# Progress on atom interferometry in a marginally stable cavity

Dylan Sabulsky

*LP2N, Laboratoire Photonique, Numérique et Nanosciences, Université Bordeaux–IOGS–CNRS*

We propose a marginally stable optical resonator suitable for atom interferometry. The resonator geometry is based on two flat mirrors at the focal planes of a lens that produces the large beam waist required to coherently manipulate cold atomic ensembles. The resulting power build-up will allow for enhanced coherent manipulation of the atomic wavepackets such as large separation beamsplitters. We study how to implement atom interferometry based on Large Momentum Transfer Bragg diffraction in such a cavity and demonstrate a horizontal multi-photon atom interferometer driven via Bragg diffraction enhanced such an optical resonator. Using a sub-Doppler cooled $^{87}$Rb source, we observe momentum transfer up to $8\hbar k$ and demonstrate inertial sensitivity using significantly reduced optical power ($< 1$mW), taking advantage of the optical gain of the cavity. Our method is applicable to a vast class of measurement geometries and atomic sources - we open a new perspective not only for the realization of high sensitivity multi-axis inertial atom sensors, but also for the future realization of hybrid atom-/optical gravitational wave detectors.

# Large-scale atom interferometry with MIGA

*LP2N, Laboratoire Photonique, Numérique et Nanosciences,*
*Université Bordeaux–IOGS–CNRS*

We report the realization of a large scale gravity antenna based on matter-wave interferometry, the MIGA project. This experiment consists in an array of cold Rb sources correlated by a 150 m long optical cavity. MIGA is in construction at the LSBB underground laboratory, a site that benefits from a low background noise and is an ideal premise to carry out precision gravity measurements. The MIGA facility will be a demonstrator for a new generation of GW detector based on atom interferometry that could open the infrasound window for the observation of GWs. We describe here the status of the instrument construction, focusing on the infrastructure works at LSBB and the realization of the vacuum vessel of the antenna.

# (TaSe4)3I: Reconciling transport, optics and ARPES

Irián Sánchez Ramírez

Recently, the quasi one-dimensional transition metal tetrachalcogenide (TaSe4)3 I has been found to display the coexistence between superconductivity and ferromagnetism. This result is conflicted with the previous works on this material, which overall predict it to be insulating. Furthermore, no consensus exist on the electronic properties of (TaSe4)3I in the literature, since ARPES and transport measurements disagree by an order of magnitude on its electronic bandgap. In this work, we rationalize the observed transport gaps and reconcile them with ARPES and optical experiments by relating the dissimilarities with band-folding due to an approximated translational symmetry due to distortion caused by Se cages. Finally, we relate the observed superconducting behavior to a possible extrinsic hole doping which can tune the Fermi level through a Van Hove singularity.

# Linear and nonlinear optical responses of chiral multifold semimetals

Miguel Ángel Sánchez Martínez

The traditional classification of fermions can be enhanced in solid-state systems with additional fermionic excitations, known as multifold fermions, protected by crystal symmetries. We calculate the linear optical conductivity of all chiral multifold fermions and study the multifold semimetals CoSi and RhSi using realistic tight-binding models and DFT, allowing us to characterize the materials, explain their optical conductivity, and estimate the second-harmonic generation of RhSi.

# Electronic band structure of the Co-pnictide $CaCo_2As_2$ probed by ARPES

[1,*]David Subires, [1]L. Sánchez, [1]M. García-Díez, [2]G. Carbone, [3]T. Yilmaz, [3]E. Vescovo,

[4] M.Shatruk, [1,5]MG Vergniory, [1,6]S. Blanco-Canosa

[1]Donostia International Physics Center (DIPC), E-20018 San Sebastián, Spain.

[2]MAX IV Laboratory, SE-221 00 Lund, Sweden.

[3]NSLS II, Brookhaven National Laboratory, Upton, New York, 11973,USA.

[4]Department of Chemistry and Biochemistry, Florida State University, Tallahassee, Florida 32306, USA.

[5]Max Planck Institute for Chemical Physics of Solids, Dresden D-01187, Germany.

[6]IKERBASQUE, Basque Foundation for Science, 48013 Bilbao, Spain.

Abstract

Topological quantum materials represent an ideal scenario where to study the interplay between different interactions that can manifest interesting micro and macroscopic properties. One of this type of materials are the Weyl semimetals whose low-energy excitations are Weyl fermions. By the bulk-surface correspondence, these materials have topological protected Fermi arcs surface states. The experimental observation of these surface states gives an unequivocal proof that a particular compound is a Weyl semimetal [1]. Here, we report the experimental band structure of the recently predicted magnetic Weyl semimetal [2] Co-pnictide $ACo_2X_2$ (A=Ca,Ce and X=P,As). We present the angle-resolved photoemission spectroscopy (ARPES) measurements and density functional theory calculations to describe the electronic band structure and the possible existence of Weyl fermions in $CaCo_2As_2$.

Email: david.subires@dipc.org

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# Understanding the normal modes of optical fibers for quantum communications

Miguel Varga[1,*], Ángel Cifuentes[1], Jon Lasa-Alonso[1,2], Carlos Maciel-Escudero[1,3], Martín Molezuelas-Ferreras[1], Iker Gomez-Viloria[1], Gabriel Molina-Terriza[1,2,4,**]

[1]Centro de Física de Materiales, Paseo Manuel de Lardizabal 5, 20018, Donostia - San Sebastián, Spain. [2]Donostia International Physics Center, Paseo Manuel de Lardizabal 4, 20018, Donostia - San Sebastián, Spain. [3]CIC NanoGUNE BRTA and Department of Electricity and Electronics, UPV/EHU, 20018, Donostia - San Sebastián, Spain. [4]IKERBASQUE, Basque Foundation for Science, María Díaz de Haro 3, 48013, Bilbao, Spain.

*e-mail: miguel.varga@ehu.eus - **e-mail: gabriel.molina@ehu.eus

In this work-in-progress we are aiming to generate a real-world quantum communications system using commercial telecom optical fibers. Recently, there have been reports of several communication protocols using single-mode optical fibers and photons discretized in polarization [1] or time-bin [2] degrees of freedom.

Here, we propose using angular momentum as our degree of freedom, i.e., using photons that are cylindrically and mirror symmetric [3] since this offers a higher degree of versatility. This kind of light has proved to be resilient against external noise [4], moreover, entangled states that are eigenstates of angular momentum are protected against cylindrically symmetric scatterers [5].

These states appear to be a natural choice for quantum communications through few-modes fibers (FMF) and in order to fully utilize them we must first be able to correctly identify and control the fiber modes. For this purpose, we have built the optical setup depicted in Fig. 1, where, using a continuous wave laser in conjunction with a spatial light modulator (SLM), we generate states with a well-defined orbital angular momentum and helicity and couple them into an optical fiber. After being transported through the FMF, the light states are measured using complete polarization tomography. This allows us to determine which states are preserved and how the incident states are couple with the normal modes of the fiber. One of our goals is to obtain the transmission matrix for the fiber and identify the normal modes, this task is very sensitive to misalignments and optical aberrations, so a procedure to correct for these must be implemented [6].

Once we have attained full control of the normal fiber modes we will continue to work towards the implementation of a quantum communications protocol that will allows us to enhance the efficiency and stability of communications when compared to current protocols.

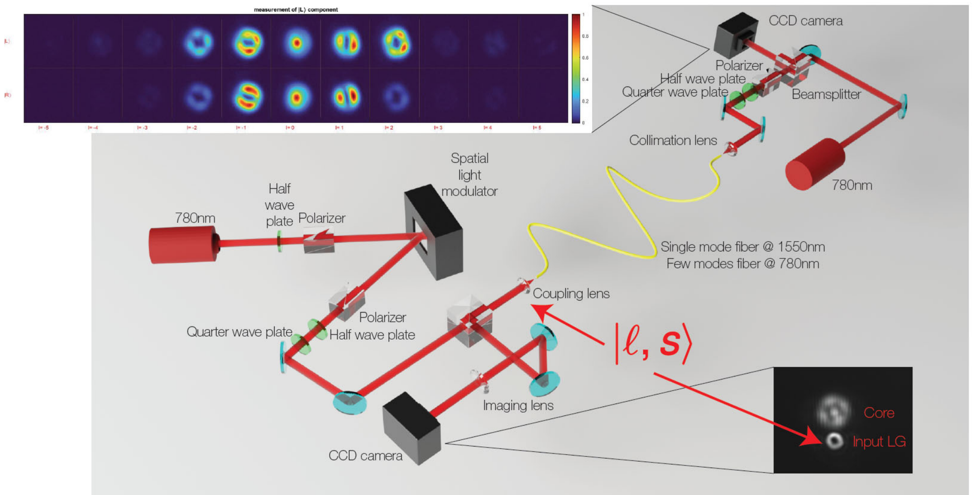


Figure 1. Experimental setup for determining the normal modes of a few-modes optical fiber.

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## 4 List of Participants

1. Alsina, Pol
   *UPV/EHU, Bilbao*

2. Arizaga Arcelus, Iñigo
   *Tecnalia, Derio*

3. Bejarano, Andrés
   *DIPC, Donostia*

4. Bercioux, Dario
   *DIPC & Ikerbasque, Donostia*

5. Bernon, Simon
   *University or Bordeaux*

6. Brodolin, Alexey
   *CFM, CSIC, Donostia*

7. Bru, Jean-Bernard
   *BCAM, UPV/EHU, and Ikerbasque, Bilbao*

8. Casanova, Jorge
   *UPV/EHU & Ikerbasque, Bilbao*

9. Cebreiro, Antonio
   *DIPC, Donostia*

10. Chen, Bo
    *DIPC, Donostia*

11. Choi, Deung-Jang
    *CFM CSIC & Ikerbasque, Donostia*

12. Cobos Jiménez, Jesús
    *UPV/EHU, Bilbao*

13. de Carvalho, Sofia Isabel
    *CFM, CSIC, Donostia*

14. de Cerio, Xabier D.
    *DIPC, Donostia*