Fluctuation-Induced Phenomena in Complex Systems

671. WE-Heraeus-Seminar

May 7 - 10, 2018
at the Physikzentrum Bad Honnef/Germany

WILHELM UND ELSE HERAEUS-STIFTUNG

Introduction

The Wilhelm und Else Heraeus-Stiftung is a private foundation which supports research and education in science, especially in physics. A major activity is the organization of seminars. By German physicists the foundation is recognized as the most important private funding institution in their fields. Some activities of the foundation are carried out in cooperation with the German Physical Society (Deutsche Physikalische Gesellschaft).

Aims and scope of the 671. WE-Heraeus-Seminar:

The study of fluctuation-induced phenomena requires an all-around perspective on how different areas of physics (e.g. thermodynamics, condensed matter theory, quantum field theory, atomic physics, quantum optics etc.) merge in the microscopic and mesoscopic world. From a theoretical point of view, combining the results of several research fields into a coherent and reliable framework can be challenging. Although each individual aspect might rely on a mature theory, the interfacing with other topics can quickly lead to difficulties but can also lead to novel interesting effects. Experimentally, despite the fact that modern techniques have allowed for a careful investigation of several of these interactions, numerous challenges appear as soon as one looks for higher accuracy or moves away from standard configurations. The aim of the seminar is to gather leading researchers working on different aspects of fluctuation-induced phenomena in order to assess the current status of this rapidly developing interdisciplinary field, to discuss future developments and to foster the exchange of concepts and techniques. The seminar targets students, postdocs and young researchers working experimentally and/or theoretically in this exciting domain of research, specifically including (but not limited to) the subtopics

- Casimir interactions
- van der Waals interactions
- Quantum and classical thermodynamics
- Dynamical nonequilibrium systems
- Nanophotonics systems

Scientific Organizers:

Dr. Francesco Intravaia	Max Born Institut & Humboldt Universität Berlin, Germany E-mail: francesco.intravaia@mbi-berlin.de
Dr. Diego A. R. Dalvit	Los Alamos National Laboratory, USA E-mail: dalvit@lanl.gov
Prof. Kurt Busch	Max Born Institut & Humboldt Universität Berlin, Germany E-mail: kurt.busch@physik.hu-berlin.de

Program

Program

Sunday, May 6, 2018

17:00 – 21:00	Registration	
19:00	*BUFFET SUPPER and get-together*	

Monday, May 7, 2018

08:00	*BREAKFAST*	
08:45 – 09:00	Scientific organizers	**Opening remarks and presentation of the seminar**
09:00 – 10:00	Ricardo Decca	**Measurement of the Casimir interaction from 0.2 to 8 microns: What we know and what we don't**
10:00 – 11:00	Ho Bun Chan	**Measurement of the Casimir force between two rectangular gratings**
11:00 – 11:30	*COFFEE BREAK*	
11:30 – 12:00	Philip Kristensen	**Repulsive Casimir-Polder forces with a non-local material response**
12:00 – 12:30	Daniel Bloch	**When atom and surface fluctuations couple: Casimir-Polder interaction for atoms resonantly coupled to thermally populated surface polaritons**
12:30 – 12:40	**Conference photo** (in the front of the lecture hall)	
12:40	*LUNCH (followed by coffee and/or tea)*	

Program

Monday, May 7, 2018

14:00 – 14:30	Philipp Schneeweiß	**Ground state cooling of atoms 300 nm away from a hot surface**
14:30 – 15:00	András Vukics	**The theory & experimental realization of photon-blockade breakthrough as a first-order dissipative quantum phase transition**
15:00 – 16:00	Karin Jacobs	**Adhesion, adsorption, wetting and friction are influenced by van der Waals forces: Old theory - new experiments**
16:00 – 16:30	*COFFEE BREAK*	
16:30 – 17:30	Lilia Woods	**Casimir physics surprises in the graphene family**
17:30 – 18:30	Rudolf Podgornik	**Hydrodynamic fluctuation stresses mediated across a randomly driven fluid film**
18:30 – 19:00	Yehuda B. Band	**Dynamics of a magnetic needle in a magnetic field: Landau-Lifshitz-Gilbert dissipation and fluctuations**
19:00 – 19:15	Stefan Jorda	**About the Wilhelm and Else Heraeus Foundation**
19:30	*DINNER*	

Program

Tuesday, May 8, 2018

07:30	*BREAKFAST*	
08:30 – 09:30	Ferdinand Schmidt-Kaler	**Quantum states of trapped ions sensing fuctuation-induced phenomena**
09:30 – 10:30	Thomas Schweigler	**Higher-order correlations and what we can learn about the solution for many body problems from experiments**
10:30 – 11:00	Tim Herpich	**Collective power: Minimal model for thermodynamics of nonequilibrium phase transitions**
11:00 – 11:30	*COFFEE BREAK*	
11:30 – 12:00	Raul Esquivel-Sirvent	**Thermal band-gaps and Fano resonances in the near field radiative heat transfer**
12:00 – 12:30	Carsten Henkel	**Non-equilibrium Rytov electrodynamics with electrons and phonons**
12:30	*LUNCH (followed by coffee and/or tea)*	

Program

Tuesday, May 8, 2018

14:00 – 15:00	Aleksandr Volokitin	**Fluctuation-electromagnetic phenomena under dynamic and thermal nonequilibrium conditions**
15:00 – 16:00	F. Javier García de Abajo	**Ultrafast processes triggered by plasmon fluctuations**
16:00 – 16:30	*COFFEE BREAK*	
16:30 – 17:00	**Poster flashes**	
17:00 – 19:30	**Poster session**	
19:00	*DINNER*	

Program

Wednesday, May 9, 2018

08:00	*BREAKFAST*	
09:00 – 10:00	Peter Hänggi	**The ring of Brownian motion: The good, the bad and some simply silly**
10:00 – 11:00	Clemens Bechinger	**Swarming, orientation and quorum sensing of synthetic microswimmers**
11:00 – 11:30	*COFFEE BREAK*	
11:30– 12:00	Boris Müller	**Oscillating modes of driven colloids in overdamped systems**
12:00 – 12:30	Alessio Squarcini	**Critical Casimir interaction between generalized colloidal Janus particles in two spatial dimensions**
12:30	*LUNCH (followed by coffee and/or tea)*	

Program

Wednesday, May 9, 2018

14:00 – 14:30	Francisco Diego Mazzitelli	**Dynamical Casimir effect: Superconducting resonators and moving mirrors**
14:30 – 15:00	Itay Griniasty	**Classical analogue of the Unruh effect**
15:00 – 16:00	Bei-Lok Hu	**Nonequilibrium atom-field-medium interaction: A unified theoretical framework for fluctuation forces, quantum friction, and quantum optomechanics**
16:00 – 16:30	*COFFEE BREAK*	
16:30 – 17:30	Ron Folman	**Fluctuations on the atom chip**
17:30 – 18:30	Giovanna Morigi	**Collective dynamics of atomic ensembles due to long-range optomechanical forces**
18:30 – 19:00	Philipp Haslinger	**Atom interferometry probes inertial properties of blackbody radiation**
19:00	*HERAEUS DINNER* *(social event with cold & warm buffet and complimentary drinks)*	

Program

Thursday, May 10, 2018

08:00	*BREAKFAST*	
09:00 – 10:00	Shanhui Fan	**Near-field energy and momentum transfer between bodies with non-reciprocal materials or out of local equilbrium**
1 :00 – 11:00	Arno Rauschenbeutel	**Chiral quantum optics**
11:00 – 11:30	*COFFEE BREAK*	
11:30– 12:00	Ryan O. Behunin	**Fundamental noise dynamics in Brillouin lasers**
12:00 – 12:30	Roberto Passante	**Detection of the Unruh effect through radiation-mediated interactions between accelerating atoms**
12:30	*LUNCH (followed by coffee and/or tea)*	

End of the seminar and departure

NO DINNER for participants leaving on Friday morning

Posters

Posters

Kiryl Asheichyk	**Heat radiation and transfer in closed systems**
Zahra Babamahdi	**Casimir force measurement in complex system**
Robert Bennett	**Lateral Van der Waals force**
Salvatore Butera	**Mechanical back-reaction form dynamical Casismir effect**
Megan Chambellan	**Forward brillouin scattering in carbon disulfide liquid core fiber optics**
Christoph H. Egerland	**Contribution of Polaritonic modes to the zero-temperature Casimir interaction of graphene**
Nima Farahmand Bafi	**Patchy particles in critical fluids**
Johannes Fiedler	**Dispersion forces in continuous media**
Giuseppe Fiscelli	**Energy transfer and resonance interaction between two identical atoms in a perfectly conducting cylindrical waveguide**
Janine Franz	**The quantum zeno effect in the local photoionisation of a BEC**
Yaroslav Gorbachev	**The photon BEC in arbitrary geometries by means of QED treatment: Coupled dissipative dynamics of dye molecules**
Michael Hartmann	**Plasma versus drude modeling of the Casimir force: Beyond the proximity force approximation**

Posters

Vinicius Henning	**Beyond the PFA regime in the plane wave basis**
Ryan Jones	**Modified dipole-dipole interaction and dissipation in an atomic ensemble near surfaces**
Matthias Krüger	**Oscillations in driven overdamped systems**
Yair Margalit	**Realization of a complete Stern-Gerlach interferometer**
Marty Oelschläger	**Dispersion forces with multilayer structures**
Dennis Rätzel	**The dynamical Casimir effect in Bose-Einstein condensates and the measurement of oscillating gravitational fields**
Daniel Reiche	**Dissipation in fluctuation-induced atom-surface interactions**
Lucia Rizzuto	**Resonance dipole-dipole interaction between two identical atoms near a perfect conducting plane boundary**
Christian Rohwer	**Non-equilibrium forces following temperature / activity quenches in classical fluids**
Felipe Rosa	**Rigorous analysis of Casimir and van der Waals forces on a silicon nano-optomechanical device actuated by optical forces**
Ephraim Shahmoon	**Electronic zero-point fluctuation forces inside circuit components**

Posters

Kanupriya Sinha	**Collective effects in Casimir-Polder forces**
Heino Soo	**Fluctuational electrodynamics for nonlinear materials**
Benjamin Spreng	**Proximity force approximation and specular reflection: Application of the WKB limit of Mie scattering to the Casimir effect**
Justin H. Wilson	**Tidal and nonequilibrium Casimir effects in a falling Casimir apparatus**

Abstracts of Talks

(in chronological order)

Measurement of the Casimir interaction from 0.2 to 8 microns: what we know and what we don't

Ricardo S. Decca[1]

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The measurement of the Casimir interaction between a R = 150 m Au-coated sphere mounted on a mechanical torsional oscillator (MTO) and a Au-coated Si sample will be presented. The Si sample is engineered such that deep trenches (from 75 to 150 microns deep) are made by Deep Reactive Ion Etching (DRIE) and subsequently coated with Au. Trenches and regions without them alternate in a periodic fashion, each Au-covered region and trench subtending the same angle. On a given sample different angular regions have been used, which facilitate detecting systematic effects. By rotating the Au-covered Si sample, there is a time dependent Casimir force felt by the sphere-MTO assembly, it alternatively seeing a Au surface or vacuum (because the contribution of the Casimir interaction over the trench is negligible). By judicious frequency and phase discrimination the Casimir interaction has been obtained. Due to the high sensitivity of the MTO, a signal to noise ratio of one can be observed for separations in excess of 10 microns. A quantitative analysis of the interaction can be achieved for separations of up to 6 microns. In the talk the sample preparation, experimental setup (including modifications to an existing system), systematic signals detection and how they are dealt with, and a comparison of the experimental results with theory will be presented. Future directions of experimental research in Casimir physics using this and other approaches will also be briefly discussed.

Measurement of the Casimir force between two rectangular gratings

Ho Bun Chan[1]

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Presentation type: Invited Speaker

One of the remarkable properties of the Casimir force is its non-trivial dependence on the shape of the interacting objects. Experiments using the corrugated surface of gratings [1, 2] have demonstrated the deviation of the Casimir force from the proximity force approximation. In these experiments one of the bodies was chosen to be a sphere to circumvent alignment difficulties. Here, we present measurement of the Casimir force gradient between two silicon structures, both of which contain rectangular corrugations. By using lithography to define the structures [3, 4], they are aligned to allow the two gratings to interpenetrate when the separation between them is reduced. Our data shows a number of novel features, including strong deviations of the force gradient from the proximity force approximation and a non-zero, distance-independent Casimir force over certain range of displacement.

References

[1] H. B. Chan, Y. Bao, J. Zou, R. A. Cirelli, F. Klemens, W. M. Mansfield and C. S. Pai, *Measurement of the Casimir force between a gold sphere and a silicon surface with nanoscale trench arrays*, Phys. Rev. Lett. **101**, 030401 (2008).

[2] F. Intravaia, S. Koev, I. W. Jung, A. A. Talin, P. S. Davids, R. S. Decca, V. A. Aksyuk, D. A. R. Dalvit and D. Lopez, *Strong Casimir force reduction through metallic surface nanostructuring*, Nat. Comm. **4**, 2515 (2013).

[3] J. Zou, Z. Marcet, A. W. Rodriguez, M. T. H. Reid, A. P. McCauley, I. I. Kravchenko, T. Lu, Y. Bao, S. G. Johnson and H. B. Chan, *Casimir forces on a silicon micromechanical chip*, Nat. Comm. **4**, 1845 (2013).

[4] L. Tang, M. Wang, C. Y. Ng, M. Nikolic, C. T. Chan, A. W. Rodriguez and H. B. Chan, *Measurement of non-monotonic Casimir forces between silicon nanostructures*, Nat. Photon. **11**, 97 (2017).

Repulsive Casimir-Polder forces with a non-local material response

Philip Trøst Kristensen[1], Francesco Intravaia[1,2], and Kurt Busch[1,2]

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Presentation type: Contributed talk

Repulsive Casimir-Polder forces have been predicted for certain material structures, such as a hole in a thin plate [1] or a wedge [2], for which one can find a local minimum in the Casimir-Polder free energy associated with polarization in the direction perpendicular to the surface (see figure). Small feature sizes in the geometry, such as sharp edges, appear to be important for the repulsion to become manifest in the models, which were done using perfect conductors or local-response material models, such as the Drude model. Local-response material models, however, are known to break down for geometries with sharp edges, where they can lead to unphysical divergences in typical scattering calculations. This raises the question to which extent the repulsive forces are influenced by a non-local material model.

We present a numerical real-time approach for practical calculations of Casimir-Polder forces with the discontinuous Galerkin time-domain method. The real-time approach enables non-local corrections in the material model, as described by a hydrodynamical model of the conduction electrons in the metal. For the example wedge structure in Fig. 1, we assess the effect on the repulsion when increasing the non-local coupling parameter $\beta = v_F/\sqrt{3}$, where v_F is the Fermi velocity. We find, that the repulsive Casimir-Polder force is robust against β-values several orders of magnitude larger than those of realistic materials.

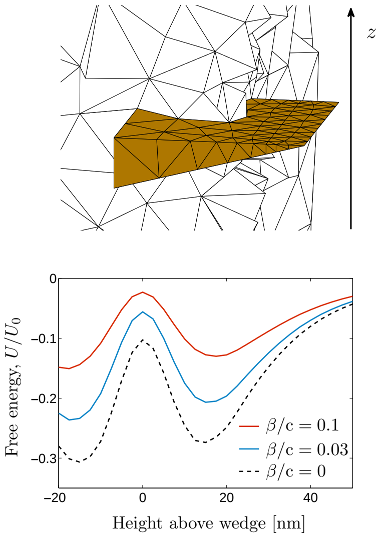

Figure 1 : Top: Example calculation mesh with a metal wedge in air. Bottom: Casimir-Polder free energy (units of $U_0 \propto \alpha_{zz}$) for a completely anisotropic particle with polarizability α_{zz} as a function of height along a line perpendicular to the surface, cf. top panel. Dashed curve shows the results using a Drude model, and blue and red curves show the impact of a non-local material response.

References

[1] M. Levin, A. P. McCauley, A. W. Rodriguez, M. T. H. Reid, and S. G. Johnson, *Casimir Repulsion between Metallic Objects in Vacuum*, Phys. Rev. Lett. **105**, 090403 (2010).

[2] K. A. Milton, E. K. Abalo, P. Parashar, N. Pourtolami, I. Brevik, and S. Å Ellingsen, *Repulsive Casimir and CasimirPolder forces*, J. Phys. A: Math. Theor. **45**, 374006 (2012).

When atom and surface fluctuations couple : Casimir-Polder interaction for atoms resonantly coupled to thermally populated surface polaritons

J. C. de Aquino Carvalho[1], A. Laliotis[1], I. Maurin[1], M. Ducloy[1], D. Bloch[1], D. de Sousa Meneses[2], P. Echegut[2]

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Presentation type: Contributed talk

The Casimir interaction between neutral surfaces, and its atom-surface version for the Casimir-Polder (C-P) interaction, are key examples of fundamental effects of vacuum fluctuations in electrodynamics. An extra degree of complexity appears when the vacuum is not considered to be at T= 0, and the near-field contribution of the thermal emission [1] cannot be neglected for these Casimir-type interactions. Hence, information about the surface modes is required, along with the atom energy structure and couplings for the C-P interaction [2]. The situation of a resonant coupling between the atom fluctuations and the surface modes [3] had been shown to possibly induce an exotic surface repulsion, and surface-induced quenching.

Presently, we analyze an experiment of selective reflection spectroscopy between Cs vapor and a hot sapphire surface, conducted freom the Cs ground state ($6S_{1/2}$) to the two $7P_{1/2}$ and $7P_{3/2}$ fine structure components. Severe differences are found as expected between the strength of the C-P interaction for the 2 lines (respectively at 459 nm and 455 nm). Indeed, only the virtual coupling $7P_{1/2} \rightarrow 6D_{3/2}$ (at 823 cm^{-1}) falls in resonance with the rather narrow surface polariton of sapphire, while the equivalent relevant couplings (in the thermal infrared) $7P_{3/2} \rightarrow 6D_{3/2}$, $6D_{5/2}$ are around 650 cm^{-1}. The knowledge on the sapphire fluctuations, including those responsible for the surface modes [4], had been usually derived through very indirect measurements: in its essence, the entire spectrum of the thermal emission or material reflectivity yields the complex bulk permittivity $\varepsilon(\omega)$ through a Kramers-Kronig evaluation. Surface modes are then extracted through resonances of $[(\varepsilon-1)/(\varepsilon+1)]$.

We plan to discuss how our C-P measurements, performed for a series of equilibrium temperature, provide an alternate and precise evaluation of the thermal quantum fluctuations affecting the sapphire surface. Although such a measurement is restricted to a sharp frequency-window, it is quite direct, with the advantage that atom probing minimizes the perturbation induced by the measurment itself.

References

[1] J.-J. Greffet *et al.* "Coherent emission of light by thermal sources", *Nature*, **416**, 61 (2002).
[2] A. Laliotis *et al.* "Casimir-Polder interactions in the presence of thermally excited surface modes" *Nat. Commun.*, **5**, 4364 (2014).
[3] H. Failache *et al.,* "Resonant van der Waals repulsion between excited Cs atoms and sapphire surface" *Phys. Rev. Lett.* **83**, 5467 (1999) and "Resonant quenching of gas-phase Cs atoms induced by surface polaritons" *Phys. Rev. Lett.* **88**, 243603 (2002).
[4] T.Passerat de Silans *et al.* ,"Temperature dependence of the dielectric permittivity of CaF_2, BaF_2 and Al_2O_3: application to the prediction of a temperature-dependent van der Waals surface interaction exerted onto a neighbouring Cs($8P_{3/2}$) atom", *J. Phys. Condensed Matter* **21** 255902 (2009).

Ground state cooling of atoms 300 nm away from a hot surface

Yijian Meng[1], Alexandre Dareau[1], Philipp Schneeweiss[1], and Arno Rauschenbeutel[1]

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Presentation type: Talk

Cold atoms coupled to light guided in nanophotonic structures constitute a powerful research platform, e.g., for probing surface forces, the study of light-induced self-organization, as well as quantum networking. The strong spatial confinement of the optical trapping fields in nanophotonic systems gives rise to significant fictitious magnetic field gradients. These can be used to perform degenerate Raman cooling (DRC), which has been pioneered in optical lattices [1].

Here, we implement DRC of atoms in a nanofiber-based optical trap [2]. Remarkably, this scheme only requires a single fiber-guided light field, which provides three-dimensional cooling. We show that continuously applying such cooling extends the lifetime of atoms in the trap by one order of magnitude. Using fluorescence spectroscopy, we precisely measure the temperature of the atoms. We find that they can be cooled close to the motional ground state despite the atoms being less than 300 nm away from the hot fiber surface [3]. This achievement sets an excellent starting point for further experiments, e.g., on the investigation of heat transfer at the nanometric scale or on probing atom–surface bound states.

References

[1] S. E. Hamann et al., Phys. Rev. Lett. 80, 4149 (1998).

[2] E. Vetsch *et al.*, Phys. Rev. Lett. **104**, 203603 (2010).

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The theory & experimental realization of photon-blockade breakthrough as a first-order dissipative quantum phase transition

J. M. Fink[1,2], A. Dombi[3], A. Vukics[3], A. Wallraff[1], and P. Domokos[3]

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Presentation type: Contributed talk

Nonequilibrium phase transitions exist in damped-driven open quantum systems when the continuous tuning of an external parameter leads to a transition between two robust steady states. In second-order transitions this change is abrupt at a critical point, whereas in first-order transitions the two phases can coexist in a critical hysteresis domain.

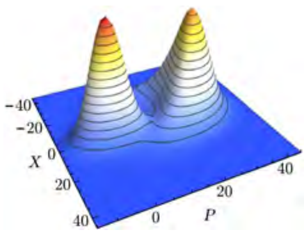

Figure 1 : Measured Q function of the stripline cavity @ the critical drive strength.

Here, I present the theoretical outlines of a first-order dissipative quantum phase transition, together with its observation in a typical driven circuit quantum electrodynamics setting [1]. The microscopic basis of the transition is that the photon blockade of the driven cavity-atom system is broken when increasing the drive power [2, 3]. The observed experimental signature is a bimodal phase space distribution (cf. Fig. 1) with varying weights controlled by the drive strength. The measurements show an improved stabilization of the classical attractors up to the millisecond range (cf. Fig. 2) when the size of the quantum system is increased from one to three artificial atoms. The formation of such robust pointer states could be used for new quantum measurement schemes or to investigate multiphoton phases of finite-size, nonlinear, open quantum systems.

References

[1] J. M. Fink, A. Dombi, A. Vukics, A. Wallraff, and P. Domokos, *Observation of the Photon-Blockade Breakdown Phase Transition*, Phys. Rev. X **7**, 011012 (2017).

[2] A. Dombi, A. Vukics, and P. Domokos, *Bistability Effect in the Extreme Strong Coupling Regime of the Jaynes-Cummings Model*, Eur. Phys. J. D **69**, 60 (2015).

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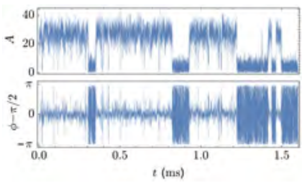

Figure 2 : A real-time single-shot record (single quantum trajectory) of the transmitted output field amplitude and phase for three atoms in resonance with the cavity.

Adhesion, adsorption, wetting and friction are influenced by van der Waals forces: old theory - new experiments

Karin Jacobs[1]

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Presentation type: Invited Speaker

Usually, Van der Waals (vdW) forces are considered weak and of short range and are therefore often neglected. However, our experiments show that vdW forces contribute significantly to a number of interfacial phenomena such as thin-film stability [1, 2], protein adsorption [3], bacterial [4, 5] and gecko adhesion [6] as well as single-asperity friction [7], and that vdW forces can be of long range. The key to an accurate description of vdW and other relevant forces in these very different systems is a precise knowledge of the interacting objects, for example their chemical composition from the surface to about 100 nm into the depth of the bulk material. The effective interface potentials for describing and understanding the different experimental situations can also serve as useful descriptions for future simulations of similar systems, which will become more precise and predictable considering the vdW interactions. In the talk I will give an overview how the experimental characterization of the dominant forces and their description succeed in these different systems.

Figure 1 : Model for bacterial adhesion: Protein as well as bacterial adhesion are influenced by vdW forces. In our experiments, bacterial adhesion is probed by single cell force spectroscopy.

References

[1] P. Loskill, H. Hhl, T. Faidt, S. Grandthyll, F. Mller, and K. Jacobs, *Is adhesion superficial? Silicon wafers as a model system to study van der Waals interactions*, Adv. Coll. Interf. Sci. **107**, 179182 (2012).

[2] J. McGraw and K. Jacobs, *Controlling wetting properties of polymers* in "Encyclopedia of Polymeric Nanomaterials", edited by S. Kobayashi and K. Mllen, ISBN 978-3-642-29647-5; Springer Heidelberg, (2016).

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[5] C. Spengler, N. Thewes, Ph. Jung, M. Bischoff, and K. Jacobs, *Determination of the nano-scaled contact area of Staphylococcal cells*, Nanoscale **9**, 10084 (2017).

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Casimir Physics Surprises in the Graphene Family

Lilia M. Woods[1], Pablo Rodriguez-Lopez[2], Wilton J. M. Kort-Kamp[3], and Diego A. R. Dalvit[3]

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Presentation type: Invited Speaker

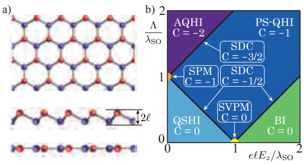

Figure 1 : (a) Top view of the 2D hexagonal lattice; side view of staggered silicene, germanene, and stanene; side view of flat graphene; (b) Phase diagram of the graphene materials in the electric field E_z – circularly polarized laser light Λ plane, normalized to the spin orbit coupling λ_{SO}. The different phases are characterized by a Chern number C.

Dirac material have become an interesting playground not only for discoveries of novel properties and effects, but also for investigating various types of interactions. The Casimir force is a universal interaction originating from electromagnetic fluctuations between objects, however, its magnitude, sign, scaling laws, and other dependences are strongly affected by the interacting systems and their extensions [1]. 2D Dirac materials, such as graphene, silicene, germanene, and stanene, offer new opportunities to re-evaluate the Casimir force functionalities and its control. These systems are representatives of the graphene class of materials and here I will present an overview of their atomic structure, energy bands, and optical response properties. The graphene family exhibits various topological phase transitions under external fields, which largely become possible due to the significant spin orbit coupling and finite staggering in silicene, germanene, and stanene (Fig. 1). Based on the Kubo formalism and low energy Hamiltonian, we compute the optical conductivity tensor for the entire phase diagram by taking into account the frequency and wave vector dependences, which are then used to describe a rich structure of the response in this family of materials [2]. The phase transitions, captured in the electronic and optical properties, strongly impact their Casimir interactions, in which novel distance scaling laws, magnitude and sign changes, and force quantizations become possible [3]. The complex interplay between Dirac physics, spin orbit coupling, and external factors in the studied 2D systems strongly suggest that materials beyond standard metals and dielectrics hold promise for fundamental discoveries in fluctuation induced interactions.

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Hydrodynamic fluctuation stresses mediated across a randomly driven fluid film

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Presentation type: Invited Speaker

I will describe fluid mediated effective interactions in a confined film geometry, between two rigid, no-slip plates, where one of the plates is mobile and subjected to a random external forcing with zero average. The fluid is assumed to be compressible and viscous, and the external surface forcing to be of small amplitude, thus enabling a linear hydrodynamic analysis. While the transverse and longitudinal hydrodynamic stresses (forces per unit area) acting on either of the plates vanish on average, they exhibit significant fluctuations that can be quantified through their equal-time, two-point correlators. For transverse (shear) stresses, the same-plate correlators on both the fixed and the mobile plates, and also the cross-plate correlator, exhibit decaying power-law behaviors as functions of the inter-plate separation with universal exponents. The same-plate stress correlator on the fixed plate increases and saturates on increase of the inter-plate separation, reflecting the non-decaying nature of the longitudinal forces acting on the fixed plate. The qualitative differences between the transverse and longitudinal stress correlators stem from the distinct nature of the shear and compression modes as, for instance, the latter exhibit acoustic propagation and, hence, relatively large fluctuations across the fluid film.

Dynamics of a Magnetic Needle in a Magnetic field: Landau–Lifshitz-Gilbert Dissipation and Fluctuations

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Contributed talk

Recently, it was predicted that the sensitivity of a precessing magnetic needle magnetometer can surpass that of present state-of-the-art magnetometers by several orders of magnitude [1]. In order to model the dynamics of a single-domain magnetic needle in a magnetic field, the dissipation of spin components not along the axis of easiest magnetization must be taken into account [2, 3]. Wherever there is dissipation, the fluctuation-dissipation theorem [4] shows that for a system that obeys detailed balance, fluctuations are also present. Fluctuations are a source of uncertainty that can affect the accuracy of the magnetometer. We calculate the dynamics of a magnetic needle in the presence of an external magnetic field and determine the uncertainty of a magnetic needle magnetometer due to the fluctuations that give rise to Gilbert damping [2, 3], i.e., interactions with internal degrees of freedom such as lattice vibrations, spin waves, and thermal electric currents. We solve the Heisenberg equations of motion for the spin, $\hat{\mathbf{S}}$, the unit vector in the direction of the axis of easiest magnetization, $\hat{\mathbf{n}}$, and the total angular momentum, $\hat{\mathbf{J}}$, in mean-field approximation [5, 6] by taking quantum expectation values of the equations, and noting that for large spin and orbital angular momentum, the standard deviation is small compared to the quantum average. When fluctuations are included, numerical solution of the stochastic equations is difficult when the anisotropy coefficient is large. Therefore we develop a perturbative solution around the adiabatic solution. Analysis of the uncertainty of the magnetic field in the limit of small and large magnetic fields will be presented.

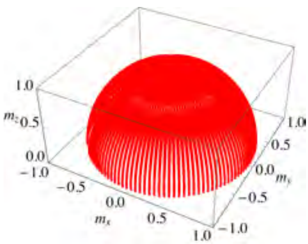

Figure 1 : Parametric plot of the needle spin unit vector $\mathbf{m}(t)$ for the high-field case.

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Quantum states of trapped ions sensing fluctuation-induced phenomena

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Single trapped ions and crystals of trapped ions exhibit outstanding coherence times [1]. At the same time, quantum states of single trapped ions, and multi-ion entangled states can be prepared, manipulated and detected almost perfectly. Therefore, such states present excellent preconditions for long, and controlled phase evolution and may be employed to detect various fluctuation-induced phenomena. For example, trapped ions allow for measuring electric field noise of nearby surfaces [2, 3]. Here, electric field sensing relies on a very sensitive detection of the motional heating once an ion had been cooled in its harmonic oscillator ground state. We have now reached a sensitivity of few phonons per second. Alternatively, a novel electric field sensor has been established using Rydberg excitations of a single ion [7]. Also, single trapped ions serve to detect magnetic fluctuations, but entanglement-enhanced sensors using ion crystals show significant advantages and reach a sensitivity of 12 pT / $\sqrt{Hz}$ [5, 4]. So far, all sensing techniques have been limited to trapped ions inside the electrode structure of a Paul trap, thus with a quite limited range of technology and scientific applications. I will conclude by discussing the extraction of single ions out of the Paul trap, and focussing the beam into a nm-size focus [6], therefore opening quantum sensing for many future tasks where probes are placed ouside the Paul trap.

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Higher-order correlations and what we can learn about the solution for many body problems from experiments

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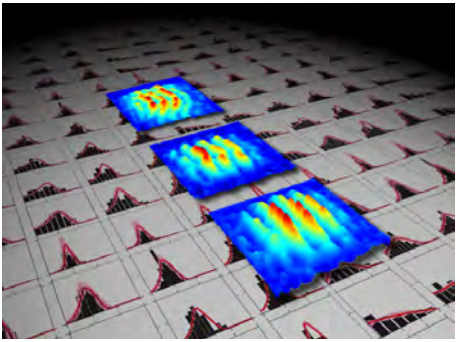
Presentation type: Invited Speaker

The knowledge of all correlation functions of a system is equivalent to solving the corresponding quantum many-body problem. If one can identify the relevant degrees of freedom, the knowledge of a finite set of correlation functions is in many cases enough to determine a sufficiently accurate solution of the corresponding field theory. Complete factorization of the correlation functions is equivalent to identifying the relevant degrees of freedom where the Hamiltonian becomes diagonal. We will give examples on how one can apply this powerful theoretical concept in experiments.



After a splitting quench, the system of two 1-dimensional quantum gases relaxes to a pre-thermalized state [1]. A detailed study of non-translation invariant correlation functions reveals that this state is described by a generalized Gibbs ensemble [2]. This is verified through phase correlations up to 10th-order. Interference in a pair of tunnel-coupled one-dimensional atomic superfluids, which realize the quantum Sine-Gordon / massive Thirring models, allows us to study if, and under which conditions, the higher correlation functions factorize [3]. This allows us to characterize the essential features of the model solely from our experimental measurements: We detect the relevant quasi-particles, their interactions and the different topologically distinct vacuum-states. The experiment thus provides a comprehensive insight into the components needed to solve a non-trivial quantum field theory. Our examples establish a general method to analyse quantum systems through experiments. It thus represents a crucial ingredient towards the implementation and verification of quantum simulators.

Work performed in collaboration with E. Demler (Harvard), Th. Gasenzer und J. Berges (Heidelberg). Supported by the Wittgenstein Prize, the Austrian Science Foundation (FWF): SFB FoQuS: F40-P10 and the EU: ERC-AdG QuantumRelax.

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Collective power: Minimal model for thermodynamics of nonequilibrium phase transitions

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Presentation type: Contributed talk

Abstract

While equilibrium phase transitions are well understood, nonequilibrium phase transitions still lack a systematic treatment. Part of the reason is that a systematic theory of nonequilibrium thermodynamics was lacking. Stochastic thermodynamics [1] nowadays provides one for systems described by stochastic dynamics, but it has been mostly explored to study noninteracting systems or systems made of few interacting particles. We will use stochastic thermodynamics to explore the physics of nonequilibrium phase transitions in large ensembles of interacting systems. A motivation to do so which is of great practical importance is to understand how phase transitions, and more generally interactions, affect the performance of large ensembles of nano-machines [2].

In order to address these questions, we consider a minimal model of driven and interacting discrete oscillators [3, 4] and establish a direct connection between its linear stochastic dynamics, its nonlinear mean-field dynamics, and its thermodynamic description. This system exhibits at the mean-field level two bifurcations separating three dynamical phases: a single stable fixed point, a stable limit cycle indicative of synchronization, and multiple stable fixed points. These complex emergent behaviors are understood at the level of the underlying linear Markovian dynamics in terms of metastability, i.e. the appearance of gaps in the upper real part of the spectrum of the Markov generator. The study of the latter also resolves the apparent contradiction between the phenomenology of the mean-field dynamics and the underlying linear Markovian dynamics which ensures convergence to a unique steady state. Thermodynamically, the dissipated work of the stochastic dynamics exhibits signatures of nonequilibrium phase transitions over long metastable times which disappear in the infinite-time limit. Remarkably, it is reduced by the attractive interactions between the oscillators. When operating as a work-to-work converter, we find that the maximum power output is achieved far-from-equilibrium in the synchronization regime and that the efficiency at maximum power is surprisingly close to the universal linear regime prediction [5]. Our work builds bridges between thermodynamics of nonequilibrium phase transitions and bifurcation theory.

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Thermal band-gaps and Fano resonances in the Near-Field Radiative Heat Transfer

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Presentation type: Contributed talk

The near-field radiative heat transfer (NFRHT) between two surfaces separated by a gap can be tuned by a suitable choice of the dielectric function of the materials. For example, the near-field thermal response of mesoporous metallic sponges can be changed by varying their porosity as was recently shown [1].

Another way is using bilayers of metals or doped-semiconductors and polaritonic materials. The hybridization of gap-surface plasmon and the phonon modes of the polaritonic material changes the spectral heat flux as well as the total heat flux. One example is a bilayer formed by porous Bi and NaBr. Bi is the metal with the lowest plasma frequency. By adding pores to the Bi, its plasma frequency can be low enough to match the transverse phonon mode of the polaritonic material. The broad frequency plasmonic mode of the metal and the sharp phonon modes meet the conditions to obtain thermal Fano resonances in the spectral heat transfer. This is an antisymmetric shaped resonances where the spectral heat transfer goes down to zero and, the total heat transfer decreases significantly [2].

When both, the plasmonic and phonon thermal spectral resonances are in a frequency narrow band, no Fano resonances are observed. This happens with bilayers of doped semiconductors and polaritonic materials. In this case, it is possible to have thermal band gaps where the spectral heat transfer is suppressed. This thermal gap can be controlled by the level of doping in the semi-conductor. Finally, we show that neither plasmon-plasmon nor phonon-phonon hybridization gives rise to thermal gaps

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Non-equilibrium Rytov electrodynamics with electrons and phonons

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Presentation type: Contributed talk

The fluctuation electrodynamics developed in the 1950s by S. M. Rytov is going through a crisis, since anomalies have been confirmed in experiments since the 2000s. The Casimir force shows deviations from the temperature-dependent theory, in particular for semiconducting and magnetic materials [1, 2]. Non-contact (or "radiative") heat transfer on the 10 nm scale exceeds the non-equilibrium predictions [3] by orders of magnitude [4, 5]. These are "thermal anomalies" that can be confined to low frequency modes $\hbar\omega \leq k_B T$, dominated by thermal fluctuations [6].

Rytov's theory has been used since its conception with nontrivial temperature profiles to describe non-equilibrium situations [7, 8]. But which temperature is relevant here? It is well known that electronic degrees of freedom equilibrate with phonons only on a picosecond time scale. This process has been described with a two-temperature model, for electrons and phonons, respectively. For illustration, we present recent pump-probe experiments performed by colleagues in Potsdam [9]. We sketch a generalisation of fluctuation electrodynamics to this setting, paying attention to those degrees of freedom that are "electromagnetically active" (electrons and optical phonons).

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Fluctuation-electromagnetic phenomena under dynamic and thermal nonequilibrium conditions

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Presentation type: Invited Speaker

In recent years considerable attention has been paid to study fluctuation-electromagnetic phenomena for nonequilibrium systems [1]. This interest is due to the fact that in nonequilibrium systems it is possible to tune the fluctuation-electromagnetic phenomena that is extremely important for the design of nanoelectromechanical devices. It is necessary to distinguish several nonequilibrium situations: (1) Different parts of the system have different temperatures, but there is no relative motion between these parts. In such conditions, the Casimir-Lifshitz forces will be modified in comparison with their equilibrium values. Theoretically it was predicted and has been experimentally confirmed that the radiation heat flux between two bodies with different temperatures in the near-field region at many orders of magnitude greater than that determined by the classical Stefan- Boltzmann law. (2) Different parts of the system are in relative motion. For example, two macroscopic plates separated by a vacuum gap, slide against each other. Another example is an atom (or nanoparticle), moving or rotating over macroscopic plate. Relative motion between bodies affects the Casimir-Lifshitz forces and leads to dissipation and Casimir friction. Currently, Casimir friction attracts great attention due to the fact that it is one of the mechanisms of noncontact friction. Fluctuations of forces (and, consequently, friction) are important for ultrasensitive force registration. (3) There is no relative motion between parts of the system, but in some part of the system a DC current is induced or there is a narrow channel with a polar liquid flow. This leads to a change in strength of the Casimir force and radiation heat transfer, and the appearance of frictional drag force. Currently, the friction drag in low-dimensional structures (quantum wells, graphene) is actively studied both experimentally and theoretically due to of its importance in nanotechnology and deep theoretical problems. The friction drag effect is closely related to the Casimir friction. The results of experiments on the observation of frictional drag between quantum wells and graphene sheets, and the current-voltage dependence of graphene on the surface of the polar dielectric SiO2, were accurately described by us using theory of the Casimir friction [1]. In [2] we proposed to use effect of frictional drag for the mechanical detection of the Casimir friction force using an atomic force microscope. Recently it was shown that fluctuation-electromagnetic phenomena are strongly enhanced near singular resonance which exists due to multiple scattering of the electromagnetic waves in the condition of the anomalous Doppler effect [2, 3].

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Ultrafast Processes Triggered by Plasmon Fluctuations

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March 6, 2018

Presentation type: Invited Speaker

Thermal fluctuations of the electromagnetic field produce phenomena such as radiative heat transfer and free-space friction that we have studied in my group over the last few years [1, 2, 3]. When plasmon-supporting structures are involved, the electromagnetic field can strongly hybridize with these collective electron excitations, giving rise to energy concentration down to the nanoscale, which is understandably accompanied by strong interaction between these excitations compared to more delocalized propagating photons. For sufficiently small structures, the magnetic part of the interaction becomes irrelevant and the systems behave quasistatically, with no limit to the confinement and strength of the interaction other than the extension the electron wave functions involved in the plasmons. We have explored this regime and found the surprising result that plasmon-mediated heat transfer can become a dominant channel of heat evacuation compared with electron-phonon coupling and electron diffusion. In this talk, I will present an overview of the so-called noncontact heat transfer and discuss the regime in which it becomes ultrafast, so that a substantial amount of electronic heat is transferred between neighboring structures within hundred of femtoseconds. I will also discuss other general implications of plasmon fluctuations and some potential applications.

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The ring of Brownian motion: The good, the bad and some simply silly

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Presentation type: Invited Speaker

Since the turn of the 20-th century Brownian noise has continuously disclosed a rich variety of phenomena in and around physics. The understanding of this jittering motion of suspended microscopic particles has undoubtedly helped to reinforce and substantiate those pillars on which the basic modern physical theories are resting: Its formal description provided the key to great achievements in statistical mechanics, the foundations of quantum mechanics and also astrophysical phenomena, to name but a few. – Brownian motion determines the rate limiting step in most transport phenomena via escape events that help to overcome obstructing bottlenecks [1], does trigger firing events of neurons and in ion channels or, more generally, induces oscillatory dynamics in excitable media [2]. More recent progress of Brownian motion theory involves (i) the description of relativistic Brownian motion and its impact for relativistic thermodynamics [3], or (ii) its role for fluctuation theorems and symmetry relations that constitute the pivot of those recent developments for nonequilibrium thermodynamics beyond the linear response regime, i.e. those various nonlinear fluctuation relations [4]. Although noise is usually thought of as the enemy of order it in fact also can be of constructive influence. The phenomena of Stochastic Resonance [5] and Brownian motors [6] present two such archetypes wherein random Brownian dynamics together with unbiased nonequilibrium forces beneficially cooperate in enhancing detection and/or in facilitating directed transmission of information. The applications range from innovative information processing devices in physics, chemistry, and in physical biology to new hardware for medical rehabilitation. Particularly, those additional nonequilibrium disturbances enable the rectification of haphazard Brownian noise so that quantum and classical objects can be directed around on a priori designed routes (Brownian motors). Despite its thrilling manifold successes Brownian motion is, nevertheless, not the "Theory of Everything", as is revealed by some more doubtful applications. We conclude with an outlook of future prospects and unsolved issues.

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Swarming, Orientation and Quorum Sensing of Synthetic Microswimmers

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Presentation type: Invited Speaker

Many motile organisms have developed intriguing steering mechanisms allowing them to orientate and navigate within gravitational, chemical or light fields. Such tactic response strongly facilitates e.g., the search for food, reproduction and/or escape from unfavorable ambient conditions and is therefore an essential aspect of life. Unlike living systems (bacteria, motile cells), where tactic behavior is typically achieved by complex internal signal pathways, it is not obvious how this can be realized with synthetic microswimmers, which have much simpler internal structures. Using light-activated self-propelled particles, we demonstrate that autonomous steering in gravitational fields and light gradients can be achieved without invoking a complex internal machinery but simply by the combination of viscous forces and torques, which naturally arise during self-propulsion in liquids. In addition, we demonstrate, how to realize different types of communication rules between particles and how this affects, e.g. the cluster formation in such systems. Because the interaction between particles can be easily varied (range of interaction, local vs. non-local interactions), this allows us to study the conditions, under which cooperative phenomena such as cluster and swarm formation can be generated in active systems.

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Oscillating modes of driven colloids in overdamped systems

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Presentation type: Contributed talk

Brownian motion is a paradigmatic example of a fluctuation-induced phenomenon as it describes the random motion of (colloidal) particles induced by thermal fluctuations of the surrounding heat bath. For many years colloidal particles have served as the ideal experimental realization of such random walkers, as their relaxation times ($\sim 10^{-9}$ s) are typically well separated from the relaxation times of the (Newtonian) solvent ($\sim 10^{-14}$ s), and hence collisions with the solvent's molecules can be regarded as an entirely random process. As a consequence, even if the particles are subjected to strong external driving forces, the velocity distribution of the molecules is virtually unchanged and the thermal bath retains its equilibrium state.

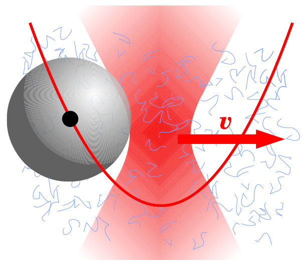

Figure 1 : Colloidal particle in a harmonic trap driven through a viscoelastic fluid.

In this joint experimental and theoretical work [1] we demonstrate that these fundamental assumptions are no longer valid for the case of viscoelastic fluids. In the experiment, we drag a colloidal particle through a worm-like micellar solution by means of an optical tweezer. Even at low driving speeds, where we still probe the linear-response regime of the solvent, the surrounding bath will be driven out of equilibrium due to its large stress relaxation time τ_s. In this stationary non-equilibrium situation a new harmonic oscillator state emerges with non-trivial fluctuations, featuring long-time correlated oscillations of several tens of seconds under the given overdamped conditions. The oscillations are accompanied by large fluctuation amplitudes that lead to a larger configurational space explored by the particle. The findings are in quantitative agreement with an overdamped Langevin equation with negative friction-memory term being equivalent to a stochastically driven underdamped oscillator with an effective mass 10^{10} the actual mass of the particle. It turns out that particle oscillations within this model are only visible within a certain range of trap stiffnesses κ. As similar effects are also observed for other viscoelastic fluids with different chemistry and microstructure, we believe the reported oscillations to be a generic feature of particles in non-equilibrium baths.

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Critical Casimir interaction between generalized colloidal Janus particles in two spatial dimensions

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Presentation type: Contributed talk

Chemically inhomogeneous colloidal particles dissolved in a critical binary mixture are subjected to a fluctuation-induced-force known as the *critical Casimir effect*. By modeling a binary mixture at its demixing critical point by means of a critical Ising model in two dimensions, and exploiting its scaling-limit description in terms of a Conformal Field Theory, we determine the *exact* density profiles around various particles whose boundaries are formed by patches with different chemical structure and preference of the binary mixture components. The formalism encompasses several interesting configurations, including Janus particles, colloidal quadrupoles (as in Fig.1) and needles with inhomogeneous patches of symmetry breaking boundary conditions. Within the framework of the "Small Particle Operator Expansion" we determine the *exact asymptotic* behavior of the interaction free energy between these colloids, and colloids confined by a wedge-shaped wall. The leading operator content associated to chemically anisotropic colloidal inclusions is captured by a series of conformal fields which we determine exactly and whose consequences are studied in detail by examining one- and two-point functions of both the order parameter and energy density in the presence of a colloid. Our theoretical predictions are confirmed by numerical results available in the literature.

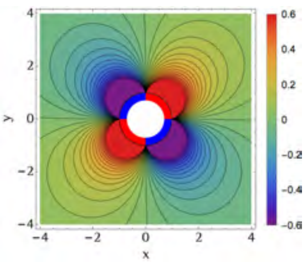

Figure 1 : Order parameter density profile around a quadrupolar Janus particle

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Dynamical Casimir effect: superconducting cavities and moving mirrors

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Presentation type: Contributed talk

We present a detailed analytical and numerical analysis of the particle creation in a cavity ended with two SQUIDs, both subjected to time dependent magnetic fields. In the linear and lossless regime, the problem can be modeled by a free quantum field in $1+1$ dimensions, in the presence of boundary conditions that involve a time dependent linear combination of the field and its spatial and time derivatives. We consider a situation in which the boundary conditions at both ends are periodic functions of time, focusing on interesting features as the dependence of the rate of particle creation with the characteristics of the spectrum of the cavity, the conditions needed for parametric resonance, and interference phenomena due to simultaneous time dependence of the boundary conditions. We pay particular attention to the analogies and differences with the case of an electromagnetic cavity with two moving mirrors. We point out several effects that could be tested experimentally, using the setup of Ref.[1]. This work is in preparation [2], and is a generalization of Ref.[3] to the case of a double tunable cavity.

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Classical analogue of the Unruh effect

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Presentation type: Contributed talk

In the Unruh effect an accelerated observer perceives the quantum vacuum as thermal radiation. This has been one of the most significant results of theoretical physics of the second half of the 20th century, but it has never been observed yet. We discovered that the Unruh effect has a deep root in the classical physics of waves. Although noise like the vacuum noise is random in space, it is organized in space-time, because it is carried by waves. This organization of wave noise creates the Unruh effect. Following this idea we performed a simple experiment with water waves where we see the first indications of a Planck spectrum in the correlation energy [1]. We have thus observed an Unruh effect for the first time.

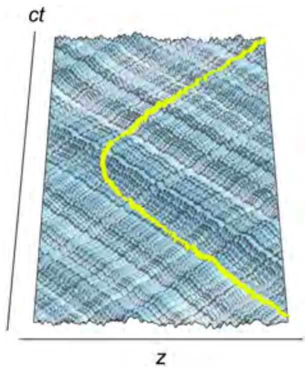

Figure 1 : Principal idea. A container is filled with water subject to noise creating ripples on the water surface. Spatial noise is organized in space time. Correlations are observed along the trajectory of an accelerated observer.

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Nonequilibrium Atom-Field-Medium Interaction: A unified theoretical framework for fluctuation forces, quantum friction, and quantum optomechanics

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Presentation type: Invited talk

We present a unified theoretical framework for studying the interaction between a moving atom or a mirror with a quantum field in the presence of a dielectric medium. A further development of work begun in [1], the topics range from a) atom-field interactions in free space at strong coupling, b) the mirror-field interactions as in the Casimir and dynamical Casimir effects, c) the atom-medium interactions as in the Casimir-Polder forces to d) *quantum friction* [2] for atoms moving near a dielectric plane, or e) the Unruh-Davies-Fulling effect for relativistic detectors in a field vacuum. We allow the harmonic atom or mirror's external (motional) and internal (electronic) degrees of freedom (dof) to be dynamical and represent the medium by a harmonic lattice. A problem studied recently with this model is that of atom-field entanglement in *quantum optomechanics* [3]. For fully nonequilibrium processes we show the added advantages of this method (see also [4]) beyond the popular macroscopic or stochastic electrodynamics approaches. In this talk based on [5] we describe the procedures for deriving the graded influence action under successive coarse-graining and describe three aspects for a stationary atom coupled to a quantum field: radiative emission in free space at strong coupling, spatial decoherence and atom-field-medium entanglement. Our next stage of work will treat a moving atom in a prescribed trajectory for quantum friction, motional decoherence and entanglement. Memory (non-Markovian) effects naturally appear in these processes as the back-action of relevant dynamical variables are treated self-consistently.

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Fluctuations on the atom chip

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Presentation type: Invited Speaker

In this presentation we will describe several forms of fluctuations on the atom chip. We will start with the effect of technical fluctuations from different sources, as well as Johnson noise arising from the surface of the chip. We will describe how they are measured and ways to address these hindering effects. We will also describe how imprecision which may be thought of as a stable yet unavoidable fluctuation limits the fidelity of quantum operations. Finally, we will also touch upon how the special features of the atom chip may be used to measure thermodynamic properties.

Collective dynamics of atomic ensembles due to long-range optomechanical forces

Giovanna Morigi[1]

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Presentation type: Invited Speaker

In this talk we will present recent theoretical work on cooling and spontaneous spatio-temporal pattern formation of atomic and molecular ensembles in optical resonators, where the key ingredient of the dynamics are the coherent and dissipative long-range optomechanical forces mediated by multiple scattering of the cavity photons. These dynamics reveal the existence of prethermalized states which are expected to be stable over the experimental time scales even in the bad cavity limit.

Atom interferometry probes inertial properties of blackbody radiation

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Presentation type: Contributed talk

Blackbody (thermal) radiation is emitted by objects at finite temperature with an outward energy-momentum flow, which exerts an outward radiation pressure. At room temperature e. g. a cesium atom scatters on average less than one of these blackbody radiation photons every 10^8 years. Thus, it is generally assumed that any scattering force exerted on atoms by such radiation is negligible. However, particles also interact coherently with the thermal electromagnetic field[1] and this leads to a surprisingly strong force acting in the opposite direction of the radiation pressure[2]. Using atom interferometry, we find that this force scales with the fourth power of the cylinder's temperature. The force is in good agreement with that predicted from an ac Stark shift gradient of the atomic ground state in the thermal radiation field[1] (see Fig.1). This observed force dominates over both gravity and radiation pressure, and does so for a large temperature range.

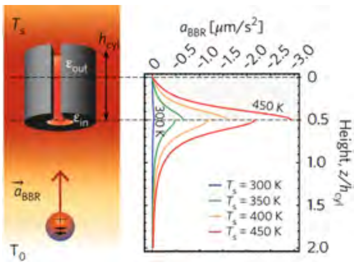

Figure 1 : The intensity gradient of blackbody radiation surrounding a heated, hollow cylinder causes a force on atoms. The cylinder is made from non-magnetic metal (tungsten) and measures 25.4mm in height and diameter. The laser light passes the cylinder through a 10mm bore to interfere the atoms. Theoretical calculation of the acceleration a_{BBR} of caesium atoms due to blackbody radiation for different temperatures T_S.

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Near-field energy and momentum transfer between bodies with non-reciprocal materials or out of local equilbrium

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Presentation type: Invited Speaker

In the vast majority of fluctuational electromagnetic study on near-field heat transfer or fluctuation-induced forces, one considers bodies made of non-reciprocal materials, and moreover one assumes that each of these bodies are in local thermal equilibrium. In this talk, we show that the use of non-reciprocal materials, or bodies that are out of thermal equilibrium, introduce new opportunities for the study of fluctuational electrodynamics. In particular, we show that a persistent heat current at equilibrium can exist in a many-body system consisting of bodies made of non-reciprocal materials.[1] We also show that with the introduction of a non-zero chemical potential, one can achieve photon-based solid-state heat pump with performance exceeding standard thermo-electric devices[2, 3], or strong repulsive non-equilibrium Casimir forces [4].

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Chiral Quantum Optics

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Presentation type: Invited Speaker

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 [2]. 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 [3]. 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 [4] or by the internal quantum state of the emitter [5], respectively. Moreover, we employed this chiral interaction to demonstrate an integrated optical isolator [6] as well as an integrated optical circulator [7] 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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Fundamental noise in Brillouin lasers

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Presentation type: Contributed talk

By harnessing coupling between light and sound, Brillouin lasers can produce ultra-narrow linewidth optical emission at multiple frequencies separated by ∼10s of GHz [1, 2, 3, 4]. These unique dynamics make Brillouin lasers ideal for applications ranging from precision rotation sensing [5] to highly-coherent microwave synthesis [2, 7, 4]. Remarkably, when implemented in micro-resonators and integrated photonic waveguides [1, 2, 3, 6, 7], fundamental sources of noise, engendered by quantum and thermo-mechanical fluctuations, determine Brillouin laser performance [3, 6, 7]. Consequently, new applications and regimes of performance may be made possible if these fundamental noise sources can be understood. In this talk, I will discuss our recent work to elucidate Brillouin laser dynamics and noise [7, 8], showing how this system can be described using coupled mode analysis and concepts of statistical physics. I will show how these results elucidate opportunities for enhanced performance, and discuss ongoing work aiming to use Brillouin lasers to synthesize microwave signals with quantum-limited coherence.

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Detection of the Unruh effect through radiation-mediated interactions between accelerating atoms

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Presentation type: Contributed talk

Abstract

We consider the resonance and dispersion (Casimir-Polder) interactions between two atoms moving with a uniform acceleration and coupled to the scalar or electromagnetic field in the vacuum state, and the relation with the Unruh effect. We investigate how the accelerated motion of the atoms modifies these radiation-mediated interactions, allowing us to obtain an indirect evidence of the Unruh effect.

We first consider the van der Waals/Casimir-Polder interaction between two neutral ground-state atoms, uniformly accelerated in the same direction and separated by a constant distance orthogonal to their trajectories. The atoms interact with the scalar or the electromagnetic field in the vacuum state. We find that the Casimir-Polder interaction energy between the two accelerating atoms has a different distance dependence compared to the case of inertial atoms, as well as a time dependence. We also show that the Casimir-Polder force between the two uniformly accelerated atoms exhibits a transition from the short distance thermal-like behavior predicted by the Unruh effect, to a long distance non-thermal behavior. Our findings indicate that the change of the Casimir-Polder interaction due to acceleration could be a suitable method to detect the Unruh effect without necessity of the extremely high accelerations necessary for other radiative effects such as the Lamb shift.

We then consider the resonance dipole-dipole interaction between two uniformly accelerated atoms, one excited and the other in the ground state, prepared in a symmetric or antisymmetric entangled state, interacting with the quantum electromagnetic field in the vacuum state. By separating the contributions of vacuum fluctuations and radiation reaction to the time evolution of atomic observables, we show that Unruh thermal fluctuations do not affect the resonance interatomic interaction, which is exclusively related to the source fields (radiation reaction). Beyond a characteristic length, non-thermal effects in the radiation reaction contribution modify the distance dependence of the dipole-dipole interaction energy compared to the case of atoms at rest, yielding a signature of the Unruh effect.

Abstracts of Posters

(in alphabetical order)

Heat radiation and transfer in closed systems

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Presentation type: Poster

Theory of thermal radiation and radiative heat transfer is currently a rapidly developing field due to its importance for micro- and nanoscale thermal devices. However, most of the theoretical work considers the heat exchange in open systems.

In this work, we study heat radiation and transfer for spherical objects confined inside a spherical cavity or between two parallel plates. Using fluctuational electrodynamics and scattering theory [1], we derive general expressions for heat radiation and transfer for small particles in arbitrary geometries [2], including situations inside cavities. As an application, we compute the heat radiation of a sphere and heat transfer between two spheres inside a spherical cavity and show that both are enhanced by several orders of magnitude through the presence of the cavity featuring remarkable peaks as a function of the cavity's radius (see Fig. 1). Furthermore, we investigate the heat emission of a particle placed between two parallel plates where an amplification and other interesting phenomena are observed.

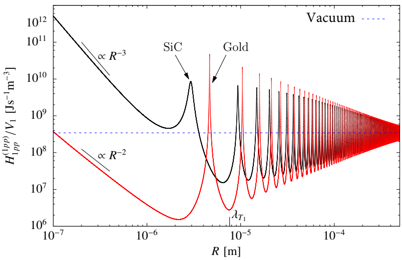

Figure 1 : Heat radiation of a particle placed inside a spherical cavity as a function of the cavity's radius.

Our results indicate a huge impact of the confinement on heat radiation and transfer and can help to create or improve technological applications as energy storage and conversion devices and thermal circuits. Moreover, the general expressions derived in this work can be applied to study further interesting scenarios of heat radiation and transfer in closed systems.

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Casimir Force measurement in Complex system

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Presentation type: Poster

Casimir interactions and their subtle interplay with chemically specific interactions and surface roughness between material surfaces are critical to understand and control structure-function relations in bonding technology. Indeed, since Casimir forces are always present in between material objects, as they originate from dipole quantum fluctuations, then an important question that we intend to answer is that can we use them to bond or assemble durable stiff materials. Since real material are imperfect conductors, the frequency dependent dielectric function must be obtained experimentally as an input in Casimir force calculations.

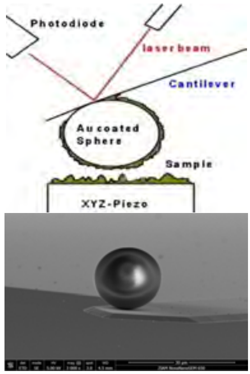

Figure 1 : AFM setup for force measurements

$$\varepsilon(i\zeta)_D = 1 + \frac{2}{\pi}\int_{\omega_1}^{\omega_2} \frac{\omega\, \varepsilon''_{exp}(\omega)}{\omega^2+\zeta^2} d\omega + \Delta_L\varepsilon(i\zeta) + \Delta_H\varepsilon(i\zeta) \quad (1)$$

$$F_C(z,T) = -kTR\sum_{n=0}^{\infty}\sum_{\upsilon=s,p}\int_0^{\infty} \ln\left(1 - r_1^{\upsilon} r_2^{\upsilon} e^{-2k_0 z}\right) q\,dq$$

In fact, AFM makes possible to measure the Casimir force, in the sphere-plate geometry and compare it with theoretical results obtained from Lifshitz theory.

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Lateral Van der Waals forces

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Presentation type: Poster

The van der Waals force is a fluctuation-mediated effect with extensive consequences across the sciences, being vital to adhesion, friction and the stability of colloids to name but a few examples. Such forces are universally assumed to act along the inter-particle separation vector — here we demonstrate that this is not necessarily the case if one considers an excited atom with a circular dipole moment interacting with an isotropically polarised ground-state atom [1]. In this case there is a force acting perpendicularly to the line joining the two atoms, which is what we term a lateral van der Waals force. The mechanism is similar to the spin-orbit coupling that leads to lateral atom-surface forces (see, for example, [2]), as indicated through the mechanical analogies shown in Fig. 1. In the talk I will outline the theory underpinning our calculation of this lateral van der Waals force, as well as provide quantitative estimates of its size and possible routes to detection. The forces predicted here will provide a new tool for optomechanical manipulation of bound systems, which should have far-reaching relevance across micro and nano electromechanical systems (MEMS/NEMS), as well as in colloidal and atomic physics.

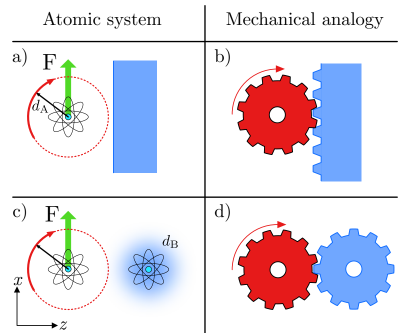

Figure 1 : Basic setup for our work, alongside mechanical analogies.

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Mechanical back-reaction from Dynamical Casimir Effect

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Presentation type: Poster

We study the quantum friction exerted on a mechanical degree of freedom, due to the creation of pairs of particles out of the vacuum because of the Dynamical Casimir Effect (DCE). We model the dynamics of system, composed by a cavity with a movable mirror, by using the Hamiltonian derived by C. K. Law in [1]. We pursue the study of the dynamics of the system by following two approaches. One makes use of an opportunely truncated set of cavity-field correlators, while the other addresses the full dynamics of the system numerically solving the master equation for the density matrix of the cavity-field system. We characterize the friction exerted from the vacuum in terms of a force damping the mechanical motion of the mirror. We find that the amount of friction is determined by both the coupling strength between the moving mirror and the (vacuum) radiation pressure, and the rate of dissipation of photons from the cavity. In the case of a high quality cavity, a novel generalized quantum friction effect is anticipated with a repeated exchange of energy between the mechanical oscillator and the electromagnetic field.

Pursuing the experimental investigation of this effect, we propose the implementation of the same physics in the context of circuit QED analogues [2]. Here the microwave magnetic field of an external LC resonator drives the effective electric length of a superconducting waveguide terminated on one end with a SQUID. We investigate the back-reaction effect of the DCE emission onto the dynamics of the resonator.

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Forward Brillouin Scattering in Carbon Disulfide Liquid Core Fiber Optics

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Presentation type: Poster

In recent years, guided acoustic wave Brillouin scattering has been harnessed to realize new forms of information processing [1], optical amplification [2, 3, 4], and laser dynamics [5]. While very low losses, long interaction lengths, and the ability to integrate with telecommunications systems make optical fibers an intriguing platform for these applications, guided acoustic wave Brillouin coupling in fiber is ordinarily very weak [6]. In this presentation, we show how carbon disulfide (CS_2) liquid core optical fibers (LCOF) [7] can be used to produce massive guided acoustic wave Brillouin couplings. This new regime of guided acoustic wave dynamics in fiber is enabled by the relatively large electrostriction and refractive index of CS_2. These properties enable single mode operation at standard telecommunications wavelengths in optical fiber with hollowed core diameter of 2 μm, yielding Brillouin scattering gains in excess of 13 $(\text{mW})^{-1}$ (>1000 $\times$ standard optical fiber), potentially enabling new forms of applications such as optical modulation, pulse compression [8], and signal processing [1].

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Contribution of polaritonic modes to the zero-temperature Casimir interaction between two graphene sheets

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Presentation type: Poster

The Casimir effect is a phenomenon where two uncharged bodies placed in vacuum attract each other due to quantum or thermal fluctuations. In addition to its fundamental interest, the Casimir force also has important technological implications, since it can cause sticking or jamming between parts of nanodevices. To control these (often unwanted) effects, one can leverage on the so-called surface polaritons, i.e. material excitations living at the surface of the bodies. In metallic systems they indeed dominate the Casimir interaction in the limit of small separations [1]. Recently, due to its prospective applications in nanotechnology, a lot of attention was devoted to the calculation of the Casimir force in graphene systems [2].

We examine in detail the contribution of the polaritonic modes to the Casimir interaction between two parallel layers of graphene. We describe the optical response of graphene within the Dirac model and we consider some specific features such as a non-vanishing band gap. Our analysis shows that, in the small distance limit, the polaritonic modes provide a constant contribution to the Casimir energy [3], which is quite contrary to comparable results obtained within the hydrodynamic model [1, 4].

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Patchy particles in critical fluids

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Abstract

Patchy colloidal particles in critical fluids provide a versatile system exhibiting tunable self–assembly. On one hand, the size and the number of chemically based patches on the particle surfaces facilitate self–assembly into well–defined structures. On the other hand, the critical Casimir interactions present in the solution provide a means to tune the strength of their interactions. By using the Derjaguin approximation, we study the effective critical Casimir potential between patchy colloidal particles. The results of these studies provide not only the universal scaling func-tions describing these interactions but also enable one to investigate the ensuing self–assembly via numerical simulations.

Dispersion Forces in continuous media

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Presentation type: Poster

Dispersion forces, such as Casimir forces between two macroscopic bodies, Casimir-Polder forces between a polarisable particle and a macroscopic body, and van der Waals forces between two polarisable particles, are induced by the ground-state fluctuations of the electromagnetic field [1]. These fluctuations spontaneously induce dipole moments in the particle or the dielectric body, which then can interact with other particles. Typically, these interaction are expressed by an exchange of virtual photons propagating through the space governed by Maxwell's equations like real photons.

Usually, particles and bodies with hard boundary conditions are considered, which is valid for typical laboratory settings. However, turning the perspective to chemical, biological or in general natural situations, where these forces play an important role, one observes that this restriction is usually not valid anymore. For instance, take two two van der Waals-interacting particles embedded in water which is a typical environment for natural chemical reactions. Due to Pauli blocking, the particles are not in immediate contact with the medium, which creates a real cavity around each particle. By solving the Poisson equation for the electric field, one finds further that the surrounding water particles forms layers leading to a radially symmetric dielectric profile [2].

We investigate the dependency of the dispersion forces in continuous media and present the influence of planarly layered media [3]. As an example, we consider a multi-layer system with continuous boundaries. By adding particles to this system, one finds examples for van der Waals and Casimir-Polder forces. Further, we show an approximation method to estimate the impact of the continuous profile effectively.

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Energy transfer and resonance interaction between two identical atoms in a perfectly conducting cylindrical waveguide

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Abstract

We consider the energy transfer between two identical two-levels atoms, one excited and the other in its ground state, interacting with the quantum electromagnetic field in the vacuum state, inside a perfectly conducting cylindrical waveguide. Using a macroscopic quantum electrodynamic approach, we first obtain an analytical expression for the energy transfer amplitude between the two atoms in a generic structured environment as a function of the environment Green's tensor. We also investigate the resonance dipole-dipole interaction between two atoms, prepared in a symmetrical or anti-symmetrical entangled state, placed in the same external environment. We then evaluate the energy transfer and the resonance interaction energy between the atoms in a specific environment, specifically when they are placed on the axis of a perfectly conducting cylindrical waveguide. We assume that the atomic transition frequency is smaller than the waveguide cut-off frequency, and obtain the energy transfer amplitude as a function of system parameters such as the interatomic distance (near and far zone), waveguide cut-off frequency and atomic dipoles orientation. We show that, in the cases considered, the presence of the waveguide strongly suppresses both the energy transfer and the resonance interaction between the atoms. This effect is particularly relevant if the interatomic distance is larger than the atomic transition wavelength, that is in the far zone regime.

The Quantum Zeno Effect in the Local Ionisation of a Bose Einstein Condensate

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Presentation type: Poster

In quantum physics frequent measurement can suppress the dynamics within the measured system. This is called the quantum Zeno effect (QZE). The macroscopic quantum state of a Bose-Einstein condensate (BEC) is one of the few quantum systems allowing the study of the QZE in position measurement. In particular, the local ionisation of the BEC by ultrashort laser pulses is analogous to an irreversible position measurement and can therefore give rise to the QZE. In our theoretical study, we investigate the QZE in a BEC submitted to a local dissipative defect. The behaviour of this open quantum system depends on several parameters: the size of the dissipative defect, effect of inter-atomic interaction, dissipation rate, to name but a few. The quantum Zeno suppression has been quantitatively investigated by numerically solving the time-dependent Gross-Pitaevskii equation, comparing the regimes of continuous local dissipation versus pulsed position measurement. An alternative approach for an ideal BEC in one dimension allows for an intuitive insight into the QZ dynamics.

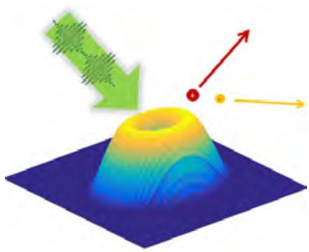

Figure 1 : Ultra short laser pulses ionise the BEC locally. This can be seen as an irreversible position measurement and can give rise to the QZE.

The photon BEC in arbitrary geometries by means of QED treatment: Coupled dissipative dynamics of dye molecules

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Presentation type: Poster

Bose-Einstein condensation (BEC) has in the last two decades been observed in cold atomic gases and in solid-state physics. Progress in photonics over the last few years has led to a new challenge in quantum optics and condensed matter: the photon BEC. This has been experimentally observed in a small microcavity filled with a dye medium [1]. Confinement of laser light within such an optical microcavity creates conditions for light to equilibrate as a gas of conserved particles. The cavity mirrors' high reflectivity guarantees that photons live long enough to scatter among dye molecules, which exchange energy with the photons by repeatedly absorbing and reemitting them. We use the language of macroscopic quantum electrodynamics [2] together with theory of open quantum systems [3] to describe this phenomenon. We are interested in the realistic description of the cavity geometry, whose frequency dependent reflection and absorption are fully encoded in the classical Green's function for the electromagnetic Helmholtz equation. This extension of the standard Jaynes-Cummings model to absorbing cavities with realistic geometries opens the door to studying the effects of coupling of discrete mode in a resonant geometry to the strong body-assisted electromagnetic field of the cavity.

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Casimir stress inside planar materials

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Presentation type: Poster

Current theory is able to predict the Casimir force between macroscopic bodies with an accuracy only limited by the knowledge of the material parameters. Yet surprisingly after almost 70 years of research, while theory describes the Casimir force between bodies, the force inside macroscopic bodies is poorly understood. We develop from a physically intuitive picture the macroscopic theory of the Casimir stress inside inhomogeneous planar media [1]. We have applied this theory to a soft wall, where the refractive index is continuous but its derivative jumps. For this situation we predict a characteristic power law for the stress inside the soft wall and close to its edges. Our result shows that such edges are not tolerated in the aggregation of liquids at surfaces, regardless whether the liquid is attracted or repelled [2].

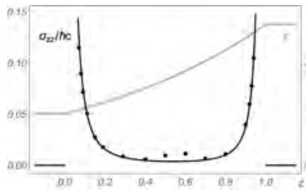

Figure 1 : Casimir stress in an inhomogeneous planar material. Numerical computation (dots) of the Casimir stress σ_{zz} for the profile $\varepsilon(z)$ of the electric permittivity shown (grey curve), $\mu = 1$ using the tools developed in [1]. The solid black curve shows an analytical prediction for the stress near each edge, in excellent agreement with the numerical results near the edges, derived in [2]. Dispersion is necessary for the convergence of the Casimir stress.

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Plasma versus Drude Modeling of the Casimir Force: Beyond the Proximity Force Approximation

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Presentation type: Poster

We calculate the Casimir force and its gradient between a spherical and a planar gold surface [1]. Significant numerical improvements allow us to extend the range of accessible parameters into the experimental regime. We compare our numerically exact results with those obtained within the proximity force approximation (PFA) employed in the analysis of all Casimir force experiments reported in the literature so far. Special attention is paid to the difference between the Drude model and the dissipationless plasma model at zero frequency. It is found that the correction to PFA is too small to explain the discrepancy between the experimental data and the PFA result based on the Drude model. However, it turns out that for the plasma model, the corrections to PFA lie well outside the experimental bound obtained by probing the variation of the force gradient with the sphere radius [2]. As shown in Fig. 1 the corresponding corrections based on the Drude model are significantly smaller than in the plasma model. However, both models violate the experimental bound for small separations L of sphere and plane.

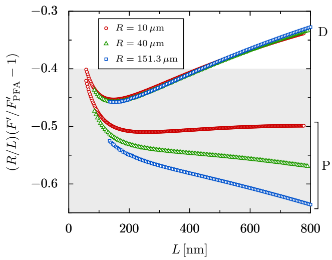

Figure 1 : Corrections to PFA for the force gradient F' at room temperature for spheres of radii R. The upper curves correspond to the Drude (D), the lower curves to the plasma (P) model. The grey area marks the parameter range experimentally excluded by [2].

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The correction to the PFA regime in the plane wave basis

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Presentation type: Poster

We have recently derived the proximity force (PF) result for the Casimir energy in the sphere-sphere and plane-sphere geometries by taking the leading order asymptotics of the exact scattering representation in the plane wave basis. A very simple interpretation based on the localization principle is suggested by this derivation (see ref.[**?**] and Benjamin Spreng's contribution). In this work we are going further in the expansion in order to derive the next-to-leading order term representing the leading correction to the PF approximation. Our approach and its corresponding simple physical picture allow us to understand if the leading correction is also spatially local, and if polarization mixing contributes to this order.

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Modified dipole-dipole interaction and dissipation in an atomic ensemble near surfaces

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Presentation type: Poster

We study how the radiative properties of a dense ensemble of atoms can be modified in a controlled way when in the presence of nearby surfaces. When the average separation between the atoms is comparable or smaller than the wavelength of the scattered photons, the coupling to the radiation field induces long-range coherent interactions based on the virtual exchange of these photons among the atoms [1]. Moreover, the incoherent scattering of photons back to the electromagnetic field is also known to be a many-body process, characterized by the appearance of superradiant and subradiant emission modes. By changing the radiation field properties, these scattering properties can be dramatically modified [2].

Starting from the master equation that describes the evolution of the system density matrix, we perform a detailed study of how the coherent and incoherent interactions in the system are modified for a pair of emitters in proximity to metal and dielectric surfaces, focussing on experimentally relevant parameter regimes. Through variation of the atomic transition frequency, the atom-surface distance and the dipole orientation, we identify the wide range of regimes that are possible in this system. We finish with an specific application in the context of quantum information storage, where the presence of a nearby surface is shown to increase the storage time of an atomic excitation that is transported across a one-dimensional chain.

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Fluctuations and responses in nonequilibrium fluids

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Presentation type: Poster

Understanding systems far from equilibrium is of fundamental and technological interest. The linear response of systems mildly perturbed from equilibrium can be understood in terms of the well known fluctuation-dissipation-theorem (FDT): The response is related to the fluctuations of the unperturbed system. For stronger perturbations, i.e., further away from equilibrium, the situation is generally less clear, and is the topic of manifold ongoing investigations.

We derive a path-integral version of nonlinear response theory [1], which can be considered an extension of the FDT to nonlinear responses. We discuss the fundamental properties of such extensions, in relation to the FDT itself. The validity and applicability of nonlinear response theory are confirmed experimentally: We determine the nonlinear (second order) response of an experimental model system from its fluctuations in equilibrium [2] (see the figure), i.e., without applying any perturbation.

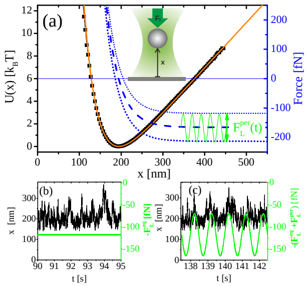

Figure 1 : Experimental setup of Ref. [2]: We demonstrate that the second order response of a Brownian particles can be determined from its equilibrium trajectories.

These path integral techniques can also be used to derive a Langevin-description for nonlinear fluids [3], from which for example the assumption of local detailed balance in driven cases can be investigated. Such descriptions are necessary to understand the motion of (driven) probe particles in (nonlinear) viscoelastic surroundings; due to the nonlinear responses of viscoelastic solvents (such as shear thinning behavior), a driven colloidal particle can display pronounced nonequilibrium fluctuations already at slow driving speeds: We will discuss a recent observation of nonequilibrium modes in such fluids, which cause a colloidal particle to oscillate in a harmonic potential, despite its overdamped nature.

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Realization of a complete Stern-Gerlach interferometer

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Presentation type: Poster

The Stern-Gerlach (SG) effect, discovered almost a century ago, has become a paradigm of quantum mechanics. Surprisingly there is little evidence that it is a fully coherent quantum process. Specifically, no high-visibility spatial interference pattern has been observed, and furthermore no full-loop SG interferometer has been realized although it has been envisioned decades ago. On the contrary, numerous theoretical studies explained why it is a near impossible endeavor. Here we demonstrate [1] for the first time both a high-visibility spatial SG interference pattern and a full-loop SG interferometer, based on an accurate magnetic field, originating from an atom chip, that ensures coherent operation within strict constraints described by previous theoretical analyses. This also allows us to observe the gradual emergence of time-irreversibility as the splitting is increased. Finally, achieving this high level of control may enable technological applications such as large-momentum-transfer beam splitting for metrology with atom interferometry, ultrasensitive probing of electron transport down to shot-noise and squeezed currents, as well as nuclear magnetic resonance and compact accelerators.

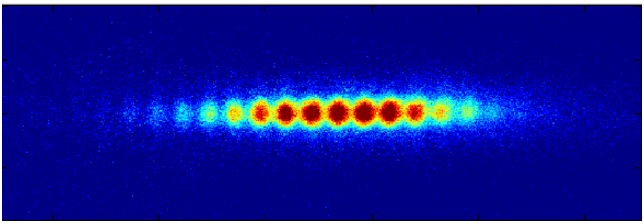

Figure 1 : A multi-shot image made of a sum (average) of 138 consecutive experimental interference images of a Stern-Gerlach interferometer, using a Bose Einstein condensate (no correction or post-selection). This result demonstrates the achieved Stern-Gerlach interferometer interference phase stability.

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Dispersion Forces with Multilayer Structures

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Presentation type: Poster

We like to present an investigation of dispersion forces on a moving microscopic object above a macroscopic, dispersive, dissipative and multilayered material. In particular we like to focus on quantum friction, a frictional force opposing the particle's motion. In our scheme we implement a freely rotating dipole at zero temperature (finite temperatures are also under current investigation) moving at constant height and with constant velocity above a flat surface. The quantum friction is substantially influence by the geometry and properties of the material's surface, which will contribute via the electromagnetic Green tensor, and the statistical measures of the system's nonequilibrium steady state (NESS). Since we use an exact solvable model for the internal particle dynamics we are able to fully include nonequilibrium contributions, which were proven to be significant for this system [1]. A crucial role concerning the strength and characteristic of quantum friction is played by the surface-plasmon polaritons, i.e. their density of states. We show how structuring the material strongly influences the plasmonic density of states and as a result changes velocity and distance dependence and further characteristics of quantum friction. Especially the coupling between the interface-plasmon polaritons within the material, yielding collective interface-plasmon polaritons, reveal interesting properties as e.g. non-local or sub-ohmic response, which we present as a way of manipulating or respectively tailoring quantum friction.

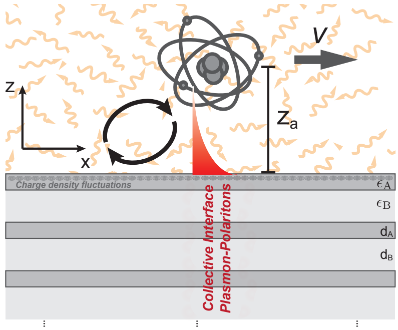

Figure 1 : An atom moves at constant velocity and height above a half-space made by alternating conductive (ϵ_A) and dielectric (ϵ_B) layers. The spectrum of vacuum fluctuations is "stuctured" through the properties of the surface and gives rise to a non-equilibrium atom-surface interaction which hinders the motion of the atom. This quantum frictional force is affected by the appearance of electromagnetic resonances due to the interlayer interaction of interface plasmon-polaritons and can be tailored by acting on the geometry and the material properties of the system.

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The dynamical Casimir effect in Bose-Einstein condensates and the measurement of oscillating gravitational fields

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Presentation type: Poster

BECs are very small and extremely cold systems of a large number of atoms. These properties are famously exploited for high precision measurements of forces with atom interferometry [1]. Another possibility of utilizing BECs as sensors for forces is to measure their effect on the collective oscillations of atoms in BECs. One specific example is the measurement of the thermal Casimir-Polder force presented in [2].

In this poster, we show how the dynamical Casimir effect in Bose-Einstein condensates [3] can be used for the measurement of oscillating gravitational fields: The curvature of the gravitational field gives rise to an effective harmonic potential. Oscillations on resonance with phonon modes of the BEC lead to squeezing of the phonon field. For gravitational fields that are strong enough, phonon pairs are created that can be, in principle, detected. For weaker gravitational fields, a squeezed probe state can be prepared and its change due to the interaction with the oscillating gravitational field may be measured. A similar measurement procedure was investigated in [4] for a gravitational wave detector. We illustrate our experimental proposal with the more easily accessible example of the gravitational field of a small oscillating gold sphere.

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Dissipation in Fluctuation-induced Atom-surface Interactions

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Presentation type: Poster

It is one of the most intriguing consequences of quantum electrodynamics that macroscopic forces can arise from the apparent "nothing"; the vacuum. Fluctuating even at zero temperature, the quantum vacuum is in no way unique, but depends on the material surrounding it. By implication, the geometry of the system and the underlying correlation lengths as well determine the fluctuation-induced forces exerted on the matter adjoining the vacuum. One prominent example of these forces is the Casimir(-Polder) force: a broad-band phenomenon – influenced by the full range of supported modes in the system – that has been found to become relevant in the construction of micro-mechanical devices. Interestingly, in certain situations, the (dissipative) low-frequency contributions of the system's mode density gain increasing impact on the relevant physical observables. Consider, for instance, the Casimir-Polder entropy at low temperature [1] or friction forces arising from dynamical nonequilibrium [2], e.g. when a particle is set into motion in close vicinity to a material interface. Here, dissipation prevails as the dominant mechanism and its exact form and origin can have important consequences on the expected behavior of the system.

Using the example of atom-surface interactions in both equilibrium and dynamical nonequilibrium, we study the distinguished role that dissipation plays in the physics of open quantum systems. We consider spatially local as well as nonlocal material models and analyze atom-surface interactions as potential candidates for testing concepts of quantum statistics. Our findings frame suitable conditions for experiments searching for yet unconfirmed effects such as quantum friction.

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Resonance dipole-dipole interaction between two identical atoms near a perfectly conducting plane boundary

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Abstract

We discuss the resonance interaction energy between two identical atoms interacting with the electromagnetic field in the vacuum state in the presence of a perfectly reflecting plate. The atoms, one excited and the other in the ground-state, are prepared in their symmetric or antisymmetric superposition. These correlated (symmetric or antisymmetric) states are the superradiant and subradiant states in the Dicke model, respectively. Following a procedure due to Dalibard, Dupont-Roc, and Cohen-Tannoudji, we separate, at the second-order in perturbation theory, the contributions of vacuum fluctuations and radiation reaction field to the resonance interaction energy between the two atoms, and show that only the source field contributes to the interatomic interaction, while vacuum field fluctuations do not. We consider specific geometric configurations of the two-atom-system with respect to the mirror, specifically two atoms aligned along a direction parallel or perpendicular to the reflecting plate. We show that the presence of the mirror significantly modifies the resonance interaction energy, yielding (for specific orientations of the two dipole moments) a change in the spatial dependence of the interaction, with respect to the case of atoms in free space. Our results indicate that the presence of a boundary can be exploited to tailor and control the resonance interaction between two atoms, as well as the related energy transfer process.

Non-equilibrium forces following temperature quenches in classical fluids: the role of fluctuations and conservation laws

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Presentation type: Poster

A rapid change of temperature ("quench") in a fluid can give rise to transient long-ranged correlations of *density fluctuations* when particle number is a conserved quantity. These correlations are predicted to lead to classical non-equilibrium *fluctuation-induced forces* (FIFs) between objects (e.g., plates) immersed in the fluid [1]. In the presence of external potentials, temperature quenches also change the fluid's spatial *mean density* profile, leading to further *density-induced forces* (DIFs) on immersed objects [2].

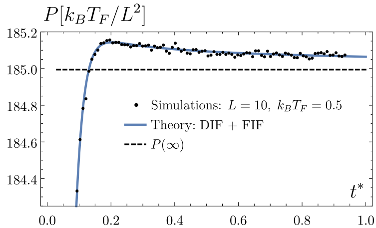

Figure 1 : Pressure P between two plates, immersed in a 2d fluid medium at a separation L, as a function of the dimensionless diffusive time $t^* = Dt/L^2$, following a quench from a randomly disordered fluid ("infinite temperature") to temperature $T_F < \infty$. Simulations are of interacting Brownian fluid particles [2].

Our recent simulations show that both FIFs and DIFs appear in a fluid of interacting Brownian particles (BPs) after a quench [2]. For passive BPs, the quench is an actual change of temperature. For active BPs, this can be mimicked by quenching the activity (effective temperature) of the fluid particles. Importantly, the latter gives rise to qualitatively similar effects as the former. While DIFs decay exponentially quickly in time, FIFs have algebraic long-time tails. To good approximation, DIFs and FIFs, which can be described using coarse-graining methods [3], are additive; see Fig. 1.

While both types of forces arise due to dynamical conservation laws, I will discuss their distinguishing features, as well as the physical conditions required for their appearance. Active matter systems, with their inherent tunability, are a promising candidate for experimental realisation of quenches and observation of the predicted post-quench forces.

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Rigorous analysis of Casimir and van der Waals forces on a silicon nano-optomechanical device actuated by optical forces

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Presentation type: Poster

Nano-optomechanical devices have enabled a lot of interesting scientific and technological applications. However, due to their nanoscale dimensions, they are vulnerable to the action of Casimir and van der Waals (dispersion) forces. This work presents a rigorous analysis of the dispersion forces on a nano-optomechanical device based on a silicon waveguide and a silicon dioxide substrate, surrounded by air and driven by optical forces. The dispersion forces are calculated using a modified Lifshitz theory with experimental optical data and validated by means of a rigorous 3D FDTD simulation. The mechanical nonlinearity of the nanowaveguide is taken into account and validated using a 3D FEM simulation. The results show that it is possible to attain a no pull-in critical point due to only the optical forces; however, the dispersion forces usually impose a pull-in critical point to the device and establish a minimal initial gap between the waveguide and the substrate. Furthermore, it is shown that the geometric nonlinearity effect may be exploited in order to avoid or minimize the pull-in and, therefore, the device collapse.

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Minimal model for the out of equilibrium optical and thermal quantum dynamics of nanoparticles

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Presentation type: Poster

In this contribution we present preliminary results on the modeling of the non-equilibrium dynamics of a metallic nanoparticle through a minimal model of oscillators and reservoirs[1].

Based on the well-known phenomenology of the dynamics of nanoparticles, we designed a composite quantum model that effectively allow us to describe the optical properties and the thermalization processes of a metallic nanoparticle (Fig.1).

We present a systematic procedure for matching the parameters of our model to different and independent physical properties of the material of the nanoparticle, such as the polarizability and the heat capacity.

We show how our model allow us to reproduce the results obtained for the thermalization of nanoparticles within the formalism of fluctuational electrodynamics. Fluctuational electrodynamics implicitly assumes that the relaxation of the phononic modes is much faster than the time scale of the thermalization process, which results in a lower bound for the time resolution of the evolution. This disables the formalism to be applied to the interaction of nanoparticles with ultra-short pulses. Our minimal model does not have this limitation and hence can predict beyond fluctuational electrodynamics.

Having a correct model for the interaction between matter and ultra-short pulses is crucial in order to contrast with the next generation of forthcoming experiments.

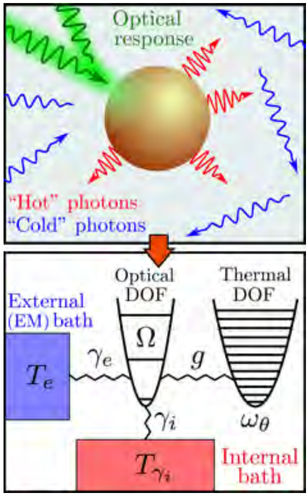

Figure 1 : (Upper) Nanoparticle in presence of an electromagnetic enviroment. (Lower) Scheme of the equivalent minimal system employed to described the dynamics of the optical and thermalization properties of the nanoparticle.

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Landauer's formula breakdown for radiative heat transfer and non-equilibrium Casimir forces

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Presentation type: Poster

In this work we analyze the incidence of the plates' thickness on the Casimir force and radiative heat transfer for a configuration of parallel plates in a non-equilibrium scenario, relating to Lifshitz's and Landauer's formulas[1]. From a first-principles canonical quantization scheme for the study of the matter-field interaction (see Ref.[2]), we give closed-form expressions for the non-equilibrium Casimir force and the heat transfer between plates of thickness $d_{\rm L}, d_{\rm R}$. We distinguish three different contributions to the Casimir force and to the heat transfer in the general non-equilibrium situation: two associated to each of the plates, and one to the initial state of the field. We analyze the dependence of the Casimir force and heat transfer with the plate thickness (setting $d_{\rm L} = d_{\rm R} \equiv d$), showing the scale at which each magnitude converges to the value of infinite thickness ($d \to +\infty$) and how to correctly reproduce the non-equilibrium Lifshitz's formula. For the heat transfer, we show that Landauer's formula does not apply to every case (where the three contributions are present), but it is correct for some specific situations. We also analyze the interplay of the different contributions for realistic experimental and nanotechnological conditions, showing the impact of the thickness in the measurements. For small thickness (compared to the separation distance), the plates act to decrease the background blackbody flux, while for large thickness the heat is given by the baths' contribution only. The combination of these behaviors allows for the possibility, on one hand, of having a tunable minimum in the heat transfer that is experimentally attainable and observable for metals, and, on the other hand, of having vanishing heat flux in the gap when those difference are of opposite signs (thermal shielding). These features turns out to be relevant for nanotechnological applications.

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Electronic zero-point fluctuation forces inside circuit components

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Presentation type: Poster

The van der Waals and Casimir forces act between electromagnetically-polarizable objects, and are often associated with the surrounding vacuum fluctuations of the electromagnetic field. However, forces induced on a physical system by the quantum zero-point fluctuations of its environment, should not be limited to those induced by the vacuum of the electromagnetic field.

We explore new opportunities offered by electronic circuit environments, for the study and characterization of quantum fluctuation forces. More specifically, we study generalized fluctuation potentials acting inside components in electrical circuits – such as forces between capacitor plates or the level shifts of superconducting qubit – all of which induced by the zero-point current fluctuations that exist in any general conductive circuit. A central theme is the ability to manipulate the electromagnetic environment experienced by a system embedded in a circuit (e.g. by simply varying a resistance/inductance coupled to the system). This results in several important and previously unexplored consequences. First, a variety of tunable fluctuation forces may arise, exhibiting for example repulsive or attractive relative forces, with a non-universal and controllable space dependence. Second, an alternative route for measuring Casimir-like forces independently of all other forces in the system, is opened, by the new possibility to measure these zero-point electronic potentials as a function of the parameters of the environment, rather than as a function of an interaction distance.

Our general approach, based on a simple macroscopic circuit theory with a proper renormalization scheme, is demonstrated for existing experimental systems of an electromechanical capacitor and a superconducting qubit. Our results of tunable potentials may be useful for future nanoelectromechanical and quantum technologies.

Collective effects in Casimir-Polder forces

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Presentation type: Poster

We study cooperative phenomena in the fluctuation-induced forces between a system of neutral two-level quantum emitters prepared in a coherent collective state and a surface. We find that the total Casimir-Polder force on the emitters can be modified via the mutual correlations between the dipoles, particularly showing that a collection of emitters prepared in a super- or sub-radiant state [1] experiences an enhanced or suppressed collective vacuum-induced force, respectively. Such collective fluctuation forces can be understood as the dispersive counterpart to collective spontaneous emission, and depend singularly on the surface response at the resonance frequency of the emitters, thus being readily maneuverable. Our results demonstrate the potential of collective phenomena as a tool to selectively tailor vacuum forces – for example, superradiant states could be used to boost and probe fluctuation forces that are otherwise too weak to be observable [2], while subradiant states that suppress undesirable Casimir-Polder attraction and exhibit long lifetimes can be potentially useful for trapping particles near surfaces.

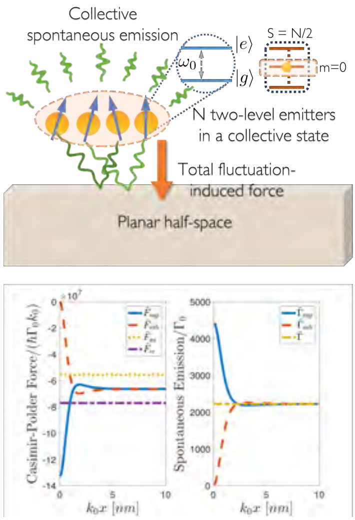

Figure 1 : A schematic representation of a collection of N two-level quantum emitters near a planar half space. We show that analogous to the collective effects in spontaneous emission, one can also modify the total vacuum-induced force on a coherent collective state of the dipoles.

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Fluctuational electrodynamics for nonlinear materials

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Presentation type: Poster

Fluctuational electrodynamics (FE) is a widely used formalism successfully applied to diverse problems, for example Casimir forces in equilibrium, but also in situations out of it, such as radiative heat transfer. All these effects depend strongly and crucially on the optical properties of the involved objects or media. These optical properties, in turn, have mostly been considered in the linear regime, described by an electric response function (or tensor), as well as its magnetic counterpart. Our aim is to extend FE to (optically) nonlinear materials.

We develop fluctuational electrodynamics for media with nonlinear optical response in and out of thermal equilibrium. Starting from the stochastic nonlinear Helmholtz equation and using the fluctuation dissipation theorem, we obtain perturbatively a nonlinear Helmholtz equation which yields the average field, the physical linear response, the fluctuations and the Rytov currents. We show that the effects of nonlinear optics, in or out of thermal equilibrium, can be taken into account with an effective dielectric function. This framework is applied in equilibrium to calculate the linear response of a combination of nonlinear objects as well as the Casimir force between them [1]. Out of equilibrium the framework is extended to handle problems such as heat radiation/transfer [2] as well as external fields [3].

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Proximity force approximation and specular reflection: application of the WKB limit of Mie scattering to the Casimir effect

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Presentation type: Poster

The electromagnetic Casimir interaction between two spheres is studied within the scattering approach using the plane-wave basis. It is demonstrated that the proximity force approximation (PFA) corresponds to the specular-reflection limit of Mie scattering. Using the leading-order semiclassical WKB approximation for the direct reflection term in the Debye expansion for the scattering amplitudes [1], we prove that PFA provides the correct leading-order divergence for arbitrary materials and temperatures in the sphere-sphere and the plane-sphere geometry. Our derivation implies that only a small section around the points of closest approach between the interacting spherical surfaces contributes in the PFA regime. The corresponding characteristic length scale is estimated from the width of the Gaussian integrand obtained within the saddle-point approximation. At low temperatures, the area relevant for the thermal corrections is much larger than the area contributing to the zero-temperature result.

References

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Tidal and nonequilibrium Casimir effects in a falling Casimir apparatus

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We consider a Casimir apparatus that is put into free fall (e.g., falling into a black hole). Working in 1+1D, we find that two main effects occur: Firstly, the Casimir energy density experiences a tidal effect: the energy density is pushed to the edge of the plates and the resulting force experienced by the plates is increased. Secondly, the process of falling is inherently nonequilibrium and we treat it as such, demonstrating that the Casimir energy density moves back and forth between the plates after being "dropped." In this way, the Casimir energy behaves like a classical liquid might, putting (negative) pressure on the walls as it moves about in its container.