Advances in Interfacial Forces and Casimir Interactions

7-9 June 2026
Aspenäs Herrgård, Gothenburg, Sweden

Abstract Booklet

The workshop is organized by Prof. Timur O. Shegai and Prof. Paulo A. Maia Neto

Welcome

Welcome to the workshop Advances in Interfacial Forces and Casimir Interactions. This booklet contains abstracts for the invited talks and the poster session.

The workshop brings together researchers working on interfacial forces, Casimir physics, and nanoscale interactions, covering both theoretical and experimental approaches, with relevance to electrolytes and nanoscale water.

The workshop is organized by Prof. Timur O. Shegai and Prof. Paulo A. Maia Neto and supported by the Knut and Alice Wallenberg Foundation and the Swedish Research Council (Vetenskapsrådet).

Practical Information

Talks

- 55 minutes (45 min presentation + 10 min discussion)
- Please check your presentation and connection at least 15 minutes before your session

Poster session

- Poster session: Monday evening (20:00–21:30)
- Posters should be installed on Monday during the lunch break or free time
- Posters must be removed no later than Tuesday at 12:00

For more information, please visit: https://shegai-lab.com/upcoming-events/

Conference Program

Day 1 – Sunday, 7 June 2026	Day 2 – Monday, 8 June 2026	Day 3 – Tuesday, 9 June 2026
	Breakfast 07:00–09:00	Breakfast 07:00–09:00
	Opening 8:50–9:00	
	Paulo A. Maia Neto 09:00–09:55 Chair: Jeremy Munday	**Jacob Klein** 09:00–09:55 Chair: Timur O. Shegai
	David S. Dean 09:55–10:50 Chair: Jeremy Munday	**Laura Fumagalli** 09:55–10:50 Chair: Timur O. Shegai
	Coffee break	Coffee break
	Hélène Berthoumieux 11:05–12:00 Chair: Jeremy Munday	**Nikita Kavokine** 11:05–12:00 Chair: Timur O. Shegai
	Lunch 12:00–13:00	Lunch 12:00–13:00
	Jeremy Munday 13:00–13:55 Chair: Paulo A. Maia Neto	**Frieder Lindel** 13:00–13:55 Chair: Tomasz J. Antosiewicz
	Sol Carretero Palacios 13:55–14:50 Chair: Paulo A. Maia Neto	**Mauro Antezza** 13:55–14:50 Chair: Tomasz J. Antosiewicz
	Coffee break	Coffee break
Arrival and Check-in 15:00–21:00	**Timur O. Shegai** 15:05–16:00 Chair: Paulo A. Maia Neto	**Oleg V. Kotov** 15:05–16:00 Chair: Tomasz J. Antosiewicz
	Group photo / Free time	Closing
Dinner 18:00–20:00	Dinner 18:00–20:00	
Arrival and Check-in	Poster session 20:00–21:30	

Invited Speakers

Monday, 8 June 2026

Tuesday, 9 June 2026

Posters

Casimir interaction with dielectrics in electrolyte solutions

Paulo A. Maia Neto[1]

[1] Physical Institute, Federal University of Rio de Janeiro, Rio de Janeiro, Brazil

Abstract
Recent experimental and theoretical results indicate that the Casimir force between dielectric particles in salted water has a longer range than previously thought. This long-range interaction results from the nonlocal response of ions in solution and has implications in molecular biology, specifically for the self-assembly of actin filaments. When considering the interaction between a dielectric and a metallic surface in salted water, the nonlocal response flips the nature of the interaction from repulsion into attraction.

Keywords: Casimir effect, nonlocal medium, biomolecular self-assembly

Dielectric response as a source of viscosity in polar liquids

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Abstract
We present a stochastic field theory for dipolar interactions in a liquid and their effect on the liquid's complex dielectric function and viscosity. The interactions remove a degeneracy present in the non-interacting dipolar system, leading to two dielectric relaxation times. We derive a Kubo relation for the linear response of a general observable to an advecting flow, and apply it to obtain a closed-form expression for the dipolar contribution to viscosity. The theoretical results are in good agreement with experimental measurements for dipolar liquids, suggesting that stochastic dipolar interactions make the dominant contribution to the viscosity of these liquids.

Keywords: van der Waals interactions, dielectrics, viscosity, stochastic field theory

The effect of water structure on hydration forces

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Abstract
The history of short-range interactions between hydrophilic surfaces, known as hydration forces, is long and complex due to the high sensitivity of experimental measurements and the strong influence of the atomic structure of the system. In particular, these forces can exhibit either oscillatory or monotonic decay depending on surface conditions, a phenomenon that remains difficult to explain within conventional theoretical frameworks.
In this work, we address this question using an extended phenomenological model based on Landau-Ginzburg theory that incorporates nonlocal correlations in polarization fluctuations of water. The model connects bulk polarization correlations with the wavenumber-dependent dielectric response of water and reproduces key qualitative features observed in molecular simulations. A central finding of this study is that a consistent description of hydration interactions requires the presence of two ranges for polarization modes in water. The first range corresponds to long-wavelength polarization fluctuations of water cluster and produces a Lorentzian-type response at small wavenumbers, reflecting large-scale dielectric screening. The second range is associated with molecular-scale structuring and layering of water near interfaces. The multiscale polarization fluctuations provides a natural explanation for oscillatory hydration forces observed between ideally smooth surfaces. At the same time, even minimal surface roughness disrupts the resonance-like mode, leading to the disappearance of oscillatory behavior and resulting in a monotonic force decay.
Thus, the model presented here offers a unified explanation for the long-standing oscillation–non-oscillation paradox in hydration forces.

Keywords: Hydration forces, surface force apparatus, polarization modes for water, roughness of the surface.

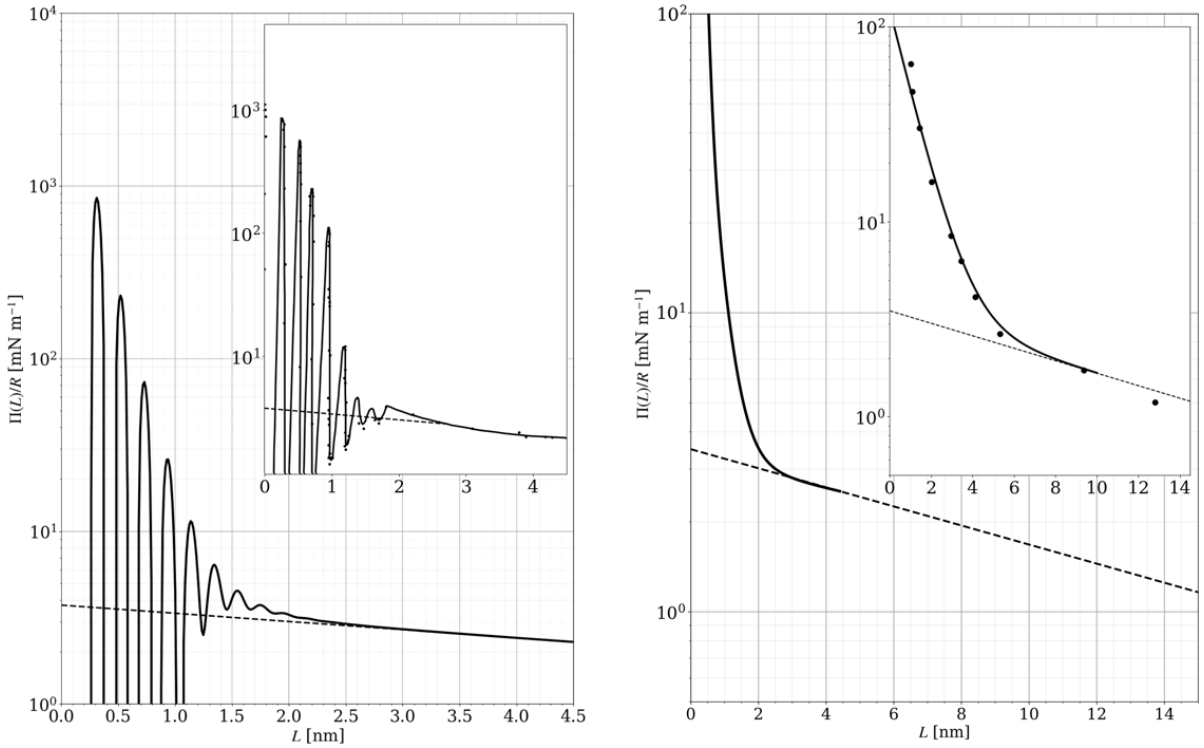

Figure 1: *Hydration force profiles calculated from our model based on bulk water polarization correlations [Hedley et al, JPC C (2023)]. The inset show experimental data from [Israelachvili et al. Nature (1993)] for the left panel and [Pashley, J. Colloid Interface Sci.]*

Controlling quantum fluctuation–induced interactions at the nanoscale

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Abstract

The Casimir effect, arising from quantum and thermal fluctuations of the electromagnetic field, provides a fundamental mechanism for generating and controlling forces and torques at nanometer-to-micron length scales. While traditionally viewed as an attractive and largely immutable interaction, recent advances in materials and nanofabrication offer new opportunities to tailor fluctuation-induced phenomena. In this talk, I will present our recent theoretical and experimental efforts to engineer Casimir interactions through material, geometric, and nonequilibrium approaches.

We will explore how nanostructuring modifies Casimir forces beyond proximity-based approximations, enabling both suppression and enhancement of interactions through tailored surface geometries. I will also discuss the role of thermal fluctuations in shaping Casimir torques, including regimes where temperature can significantly reduce or even alter the sign of the interaction. In addition, I will highlight emerging results involving biased semiconductors and conducting oxides such as indium tin oxide (ITO), where carrier density, photon chemical potential, and active modulation provide new pathways for tuning dispersion forces.

Together, these results illustrate how quantum vacuum fluctuations can be actively controlled using modern photonic materials and nanostructures. Beyond their fundamental interest, these advances open new possibilities for non-contact actuation, nanoscale devices, and the development of systems that exploit fluctuation-induced forces and torques in complex material platforms.

Casimir-Lifshitz forces governing ice premelting and interfacial water films from earth to icy worlds

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[5] Centre of Excellence ENSEMBLE3 Sp. z o. o., Wolczynska Str. 133, 01-919, Warsaw, Poland

Abstract
Quantum electromagnetic fluctuations, manifested as Casimir-Lifshitz forces,[1-3] play a fundamental role in the formation and stability of ice and water films across diverse environments. Building on the seminal work of Elbaum and Schick,[4] who demonstrated that dispersion forces can induce interfacial premelting in three-layer ice-water-vapor systems, our research extends this framework to realistic multilayer configurations including solid substrates substrates (minerals and metals) and gas-hydrate layers. We show that the sign and magnitude of fluctuation-induced forces, governed by dielectric contrast across interfaces, modulate interfacial phase behavior across environmental, technological, and planetary contexts. Investigations of gas hydrates suggest that such forces can stabilize protective ice coatings on icy worlds,[5,6] potentially impacting subsurface ocean dynamics and habitability. In parallel, analyses of metallic and oxidized interfaces reveal that surface chemistry strongly controls quantum-driven premelting phenomena, with implications for defrosting technologies.[7] These results highlight Casimir-Lifshitz interactions as a unifying mechanism governing ice evolution across complex materials and scales.

Keywords: Casimir-Lifshitz forces; Ice premelting; Multilayer interfaces; Gas hydrates; Planetary habitability; Surface chemistry

References
1 H. B. G. Casimir, Proc. K. Ned. Akad. Wet. 60, 793 (1948).
2 E. M. Lifshitz, Sov. Phys. JETP 2, 73 (1956).
3 I. E. Dzyaloshinskii, E. M. Lifshitz, L. P. Pitaevskii, Adv. Phys. 10, 165 (1961).
4 M. Elbaum and M. Schick, Phys. Rev. Lett. 66, 1713–1716 (1991).
5 M. Boström et al., Astronomy & Astrophysics 650, A54 (2021).
6 V. Esteso, et al., Self-Preservation Ice Layers Mechanisms in Mixed CO2/CH4 Gas Hydrate Systems: Implications for Icy Planetary Environments. Under revision (Astronomy & Astrophysics)
7 S. Carretero et al., Impact of Metal Oxidation on Ice Growth and Melting. Phys. Rev. B 111, 085407 (2025)

Casimir self-assembly for tunable optical microcavities

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*e-mail: timurs@chalmers.se

Abstract

In this presentation, I will show that Fabry-Pérot resonators, one of the most important workhorses of nanophotonics, can spontaneously form in an aqueous solution of gold nanoflakes [1-4]. This effect is possible due to the intricate balance between attractive Casimir-Lifshitz forces and repulsive electrostatic forces acting between the flakes. There is a hope that this technology is going to be useful for future developments in self-assembly and molecular polaritonics, as well as help develop a unified view of Casimir and strong light-matter coupling phenomena [5].

References

[1] B. Munkhbat *et al.*, Tunable self-assembled Casimir microcavities and polaritons, *Nature*, **597**, 214-219 (2021).
[2] F. Schmidt *et al.*, Tunable critical Casimir forces counteract Casimir–Lifshitz attraction, *Nat. Phys.*, **19**, 271-278 (2023).
[3] B. Kücüköz *et al.*, Quantum trapping and rotational self-alignment in triangular Casimir microcavities, *Sci. Adv.*, **10**, eadn1825 (2024).
[4] M. Hošková *et al.*, Casimir self-assembly: A platform for measuring nanoscale surface interactions in liquids, *Proc. Nat. Acad. Sci.*, **122**, e2505144122 (2025).
[5] O. Kotov *et al.*, Casimir-Lifshitz theory for cavity-modification of ground-state theory, *Phys. Rev. Lett.*, **135**, 263601 (2025).

Hydration-mediated dissipation at biological surfaces: from basics to the clinic

Jacob Klein

Molecular Chemistry and Materials Science, Weizmann Institute of Science, Rehovot, Israel

Abstract
Over the past two decades the modulation of interfacial sliding dissipation by hydration layers, where sub-nanometer water layers surrounding charges provide remarkable reduction in friction between sliding surfaces, has emerged as a key organizing principle in reducing friction in aqueous and particularly biological environments. Early work described the basic nanotribological aspects of such lubrication, while later studies identified bio-relevant vectors such as lipid bilayers as boundary lubricants. In practical terms, osteoarthritis (OA), the most common and debilitating joint disease affecting some 650 millions world wide[1] and of growing prevalence due to increasing human longevity and progressive aging of populations, is associated with friction and wear of the articular cartilage coating the joints. Strategies to alleviate this disease by reducing cartilage friction are being developed, with remarkable new technologies becoming available[2], and such approaches turn out also to be useful for novel materials properties. The talk will describe very advances and progress in exploiting biolubrication and mimicking Nature's solutions for novel treatments, including unexpected synergy of different molecular components (fig. 1). In particular, I will show very recent clinical trial results on OA alleviation, and describe how artificial intelligence/machine-learning approaches can optimize biolubrication and further alleviate this major friction-related disease.

1. WHO. "Osteoarthritis", https://www.who.int/news-room/factsheets/detail/osteoarthritis. Published 14/07/2023
2. Gomollón-Bel, F. (2024). "IUPAC's 2024 Top Ten Emerging Technologies in Chemistry." Chemistry International 46(4): 10-11.

Keywords: hydration lubrication; intra-articular dissipation and wear; osteoarthritis alleviation

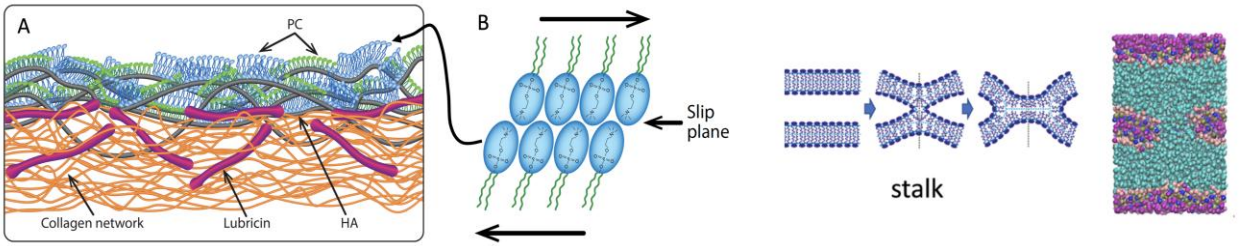

Figure 1: The remarkably low frictional dissipation at sliding articular cartilage surfaces is attributed to hydration lubrication arising at the hydrated headgroups of phosphocholine lipids coating them (left). This may break down due to stalk formation and hemifusion (right), but may be optimized by AI-aided choice of lipids, mimicking natures solutions. Use of such lipids to alleviate OA has led to remarkable results on pain alleviation in recent clinical trials[2].

Dielectric properties of water at interfaces and under atomic-scale confinement

Laura Fumagalli[1]

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Abstract
In this contribution, I will talk about our recent work in which we experimentally investigated the dielectric polarization properties of interfacial and confined water. These properties have long been subject of research because they are critical to surface forces, as well as a variety of phenomena, including ion/molecular solvation and transport, and chemical reactions. However, they have remained largely unknown for great difficulties in measuring them on the molecular scale. After briefly introducing our experimental setups that are based on advanced scanning probe methods [1-3], I will discuss our recent results in which we directly measured the local dielectric properties of water near and confined inside nanochannels made of van der Waals crystals [4,5] and near biological surfaces [6]. Our experiments revealed the presence of an interfacial water layer with dielectric properties that greatly differ from those of bulk water. Our results open up new possibilities for understanding many natural processes and provide experimental benchmarks for theories describing water-mediated interactions.

Keywords: dielectric polarization, interfacial water, confinement

References
[1] L.Fumagalli *et al. Appl. Phys. Lett.* **2007**, *91*, 243110.
[2] L.Fumagalli *et al. Nature Mater.* **2012**, 11, 808.
[3] G. Gramse *et al. Appl. Phys. Lett.* **2012**, 101, 213108.
[4] L. Fumagalli *et al. Science* **2018**, 360, 1339.
[5] R. Wang *et al*. *Nature* **2025** 646, 606–610.
[6] S. Benaglia *et al. Faraday Discuss*. **2024**, 249, 453-468**.**

Nanofluidics beyond the wall

Nikita Kavokine[1]

[1] The Quantum Plumbing Lab, EPFL, Lausanne, Switzerland

Abstract
That transport of fluids at nanometer scales has traditionally been described with continuum equations, where the confining wall plays the role of a mere boundary condition. Yet, an increasing number of experiments falls beyond such descriptions, and point to the importance of the internal dynamics of the channel wall in determining its transport properties. I will share some of my lab's recent progress in developing a "Nanofluidic Standard Model" – a field theory framework that puts all the relevant degrees of freedom in the fluid and in the channel wall on equal footing. Among other examples, I will show how charge fluctuations at the liquid-wall interface convert liquid flows into electric currents, and how phonons and hydrodynamic fluctuations conspire for nearly frictionless water transport in carbon nanotubes. Overall, I will illustrate how quantum theory tools shed light on nanoscale fluid transport.

Keywords: nanofluidics, fluctuations, friction

Casimir control of correlated electronic phases

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[2]Quantum Center, ETH Zürich, Zürich 8093, Switzerland

Abstract
Controlling correlated electronic phases through coupling to vacuum electromagnetic fluctuations provides a new route to the optical control of emergent phenomena.
In this talk, I will introduce Casimir control as a mechanism for the vacuum optical control of correlated electronic order, which arises from the dependence of the Casimir (zero-point) energy on material properties [1]. As an example, I will demonstrate how orientation-dependent Casimir energies can stabilise electronic nematic phases preferentially, particularly quantum Hall stripe orientations. For experimentally realistic parameters, the resulting Casimir-induced anisotropy exceeds previously known stabilization mechanisms by up to three orders of magnitude and we will discuss connections to recent THz experiments [2].
As an outlook, I will highlight the potential of cavity-mediated dispersion forces beyond Casimir energies for controlling correlated electronic phases.

[1] O. Carlsson, S. Chattopadhyay, J. B. Curtis, F. Lindel, L. Graziotto, J. Faist, E. Demler, Casimir Stabilization of Fluctuating Electronic Nematic Order, preprint at arXiv:2510.05088.
[2] L. Graziotto et al., Cavity QED Control of Quantum Hall Stripes, preprint at arXiv:2502.15490.

Keywords: Cavity quantum materials, Casimir control, dispersion forces in electronic system

Near-field radiative heat transfer and fluctuation forces via fast parameter modulation

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[2] Institut Universitaire de France, 1 rue Descartes, Paris, Cedex 05 F-75231, France

Abstract
We show that rapidly modulating any parameter governing near-field radiative heat exchange — such as the vacuum gap or a material's optical response — generates a quadratic, time-averaged correction to the slow thermal dynamics. This correction decomposes into a static shift and a low-frequency dynamical term, enabling modulation-induced temperature offsets and tunable effective thermal conductances capable of stabilizing or destabilizing a thermal steady state. This framework sits within the broader physics of time-varying media, where periodic driving unlocks control over transport phenomena. The same parametric philosophy extends naturally to Casimir–Lifshitz forces: fast modulation of the dielectric response or geometry is expected to produce time-averaged corrections to the force. Electrically modulated metasurfaces and driven van der Waals heterostructures emerge as compelling platforms to test these ideas.

Keywords: radiative heat transfer, Casimir-Lifshitz effect, time-varying media

Casimir-Lifshitz theory for cavity modification of ground-state energy

Oleg V. Kotov,[1, 2, 3] Johannes Feist,[2, 3] Francisco J. García-Vidal,[2, 3] and Timur O. Shegai[1].

[1] Department of Physics, Chalmers University of Technology, 412 96 Göteborg, Sweden
[2] Departamento de Física Teórica de la Materia Condensada, Universidad Autónoma de Madrid, E-28049 Madrid, Spain
[3] Condensed Matter Physics Center (IFIMAC), Universidad Autónoma de Madrid, E-28049 Madrid, Spain

Abstract
We present a theory for ground-state modifications of matter embedded in a Fabry-Perot cavity and whose excitations are described as harmonic oscillators. Based on Lifshitz's theory for vacuum energy and employing a Lorentz model for the material permittivity, we build a nonperturbative macroscopic QED model that accounts for the infinite number of cavity modes with a continuum of their wave vectors. We reveal qualitative differences from the commonly used single-mode Hopfield Hamiltonian and demonstrate the nonresonant role of polaritons in the ground-state energy shift. Using both the Lifshitz formula for imaginary frequencies and the Euler–Maclaurin formula for real ones, we showed that the cavity effect is mainly caused by static screening occurring at very low frequencies. Our theory allows for a simple inclusion of losses and temperature effects. We also provide a comparison with perturbative calculations within the Casimir-Polder theory and a method for experimental verification of the obtained results. Our theory serves as a bridge between the polaritonic and Casimir communities.

Keywords: polaritonic chemistry, Casimir effect, cavity QED

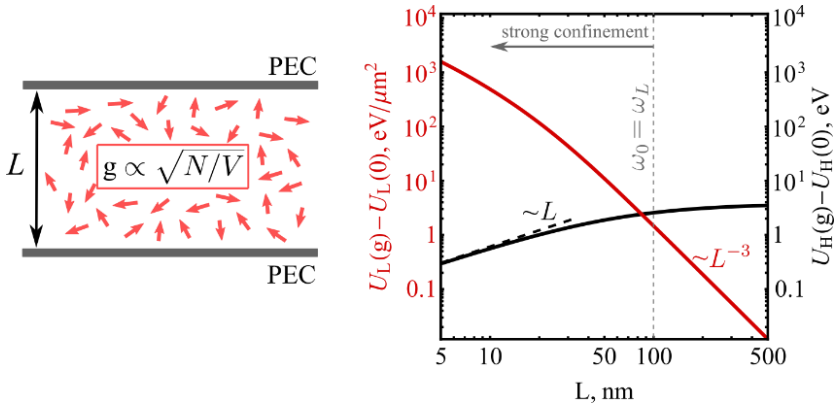

Figure 1: Sketch of the system consisting of ensemble of harmonic oscillators in a PEC cavity (left) and the ground-state energy change due to the coupling of oscillators to the vacuum EM modes, calculated using our theory and a single-mode Hopfield-like model (right). This is one of the examples showing the qualitative differences between single-mode approximation and exact infinite-mode model.

A1. Tailoring the van der Waals interaction with rotation

Helena S. G. Amaral[1 2], Patricia P. Abrantes[2], François Impens[1], Paulo A. Maia Neto[1] and Reinaldo de Melo e Souza[2]

[1] Physical Institute, Federal University of Rio de Janeiro, Rio de Janeiro, Brazil
[2] Physical Institute, Fluminense Federal University, Niterói, Brazil

Abstract
The van der Waals (vdW) force is usually attractive, but many authors have shown that by playing with the geometry and material properties of the interacting particles it is possible to achieve a repulsive interaction. In this work, we show that the rotation of the particles alone can flip the nature of the interaction — turning attraction into repulsion. We consider levitated nanoparticles made of barium strontium titanate which are driven into a fast rotation at GHz frequencies in high vacuum (see Figure 1). Repulsion is obtained by tuning the rotation frequency slightly beyond a polaritonic resonance. The change of the vdW interaction occurs because rotational Doppler shifts effectively modify the frequency-dependent polarizability of the interacting nanoparticles, thereby reshaping their mutual interaction.

Keywords: Repulsive van der Waals interaction, levitated nanoparticles, rotation

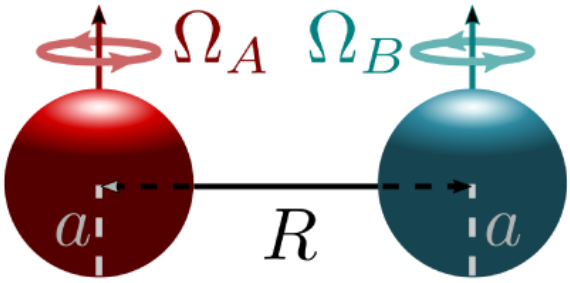

Figure 1: van der Waals interaction between spinning nanoparticles

A2. Tuning of Casimir self-assembled microcavities via laser-induced heating and radiation pressure

Arthur Luna da Fonseca[1], Oliver Svahn[1], Michaela Hošková[1], Betül Kücüköz[1], Timur Shegai[1]

[1] Department of Physics and Astronomy, Chalmers University of Technology, Göteborg, Sweden

Abstract

The Casimir Self-Assembly (CaSA) platform has established itself as a versatile framework for engineering tunable Fabry-Pérot cavities in liquid environments by balancing attractive Casimir-Lifshitz forces and screened electrostatic repulsion. In this work, we investigate how an external laser source affects the CaSA system through local heating and radiation pressure. We simulate the total interaction from the Casimir and electrostatic pressures to obtain the separation distance at which the system equilibrates. Assuming total laser absorption by the flakes to simplify momentum and heat transfer calculations, we explore external radiation pressures of up to 0.065 Pa and temperature shifts of up to 15 K provided by a laser with maximum irradiance of 2 kW /cm². Temperature landscapes are obtained with COMSOL simulations, and provide the temperature increments responsible for changing the Debye screening length of the electrostatic interaction, while leaving the Casimir interaction unaffected. Our simulations - which comply with experimental limitations like the separation distances measurement range and the relationship between surface charge density and ionic strength - reveal that the contribution of either radiation pressure or thermal modification of the electrostatic interaction is highly regime-dependent. Specifically, we find that each mechanism shifts the equilibrium separation distance by an amount that depends on the ionic strength. While the thermal modulation of the Debye screening length changes the whole electrostatic interaction and shifts the equilibrium separation distance for the entire range of ionic concentration values, the radiation pressure contribution provides a constant mechanical pressure which only affects the equilibrium for lower ionic concentration values, where the total interaction potential is less steep. This new approach to the CaSA system not only enables precise, real-time and in-situ tunability of the cavity's Fabry–Pérot resonances, but also extends the possibilities of the system to probe fundamental Casimir forces in liquid environments.

Keywords: Debye screening, Casimir effect, Radiation pressure, Laser heating

A3. Casimir self-assembly as a colloidal probe platform for measuring nanoscale interfacial forces in liquids

Michaela Hošková[1], Oleg V. Kotov[2], Betül Küçüköz[1], Catherine J. Murphy[3], Timur O. Shegai[1].

[1] Chalmers University of Technology, Physics, Gothenburg, Sweden.
[2] Universidad Autónoma de Madrid- Spain, Departamento de Física Teórica de la Materia Condensada, Madrid, Spain.
[3] University of Illinois Urbana-Champaign-, Department of Chemistry, Urbana, USA.

Abstract
Self-assembly of colloidal particles near surfaces provides a sensitive model system for studying interaction potentials in liquid environments. However, experimental approaches capable of directly probing nanoscale forces at planar interfaces remain limited, as many techniques rely on spherical particles and ensemble-averaged measurements rather than interactions at the level of individual particles. Here, we introduce Casimir self-assembly (CaSA) as a platform for probing nanoscale interfacial interactions in liquids (1). The method combines colloidal flakes forming optical microcavities with optical readout of thermally driven fluctuations through shifts of Fabry-Pérot resonances. This configuration enables direct in-situ measurements of interaction potentials between individual particles and planar surfaces. By varying electrolyte conditions, the platform allows systematic investigation of long-range interactions such as screened electrostatic double-layer repulsion and Casimir-Lifshitz attraction in electrolytes. Analysis of the particle dynamics provides access to the underlying interaction potentials and enables mapping of stability regimes and aggregation limits of micron-sized flakes near surfaces. In addition, the measured interaction potentials enable quantitative determination of surface charge densities of individual gold flakes with high sensitivity. The CaSA approach therefore provides a promising colloidal-probe platform for studying nanoscale interfacial interactions in liquids and for exploring interaction-driven self-assembly in electrolyte environments.

Keywords: Casimir effect, self-assembly, optical microcavities, thermal fluctuations, interaction potential

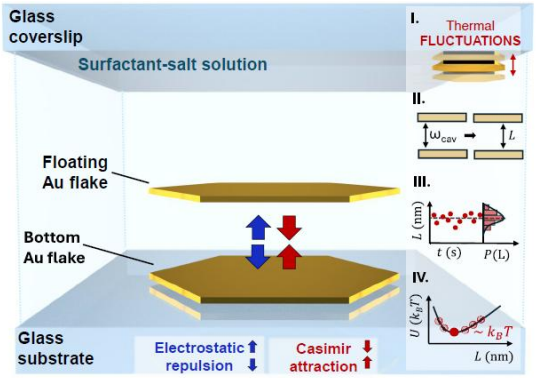

Figure 1: Schematic illustration of the CaSA platform consisting of two gold flakes: an upper fluctuating flake and a bottom static flake. Panels I–IV outline the principle of extracting the interaction potential from thermally driven motion: I) thermal motion of the upper flake, II) determination of the separation distance, III) statistical evaluation of the distance distribution, and IV) reconstruction of the interaction potential from the obtained statistics (1).

References:

[1] M. Hošková, O.V. Kotov, B. Küçüköz, C.J. Murphy, & T.O. Shegai, Casimir self-assembly: A platform for measuring nanoscale surface interactions in liquids, Proc. Natl. Acad. Sci. U.S.A. 122 (31) e2505144122, https://doi.org/10.1073/pnas.2505144122 (2025).

A4. Casimir interactions as a probe of broadband optical response

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Abstract

We report on the determination of broadband optical response from measured Casimir interactions. Using supervised machine learning to invert Lifshitz theory, we determine the complex permittivity of a material over seven orders of magnitude in frequency from a single force–distance curve. We show that the force at different separations selectively constrain distinct frequency ranges of the dielectric response, providing direct physical insight into how quantum fluctuations sample the electromagnetic spectrum. These results point towards Casimir interactions as a physically constrained, broadband spectroscopic tool and open new opportunities for optical characterization in regimes inaccessible to conventional techniques.

Keywords: machine-learning, Lifshitz theory, measurement

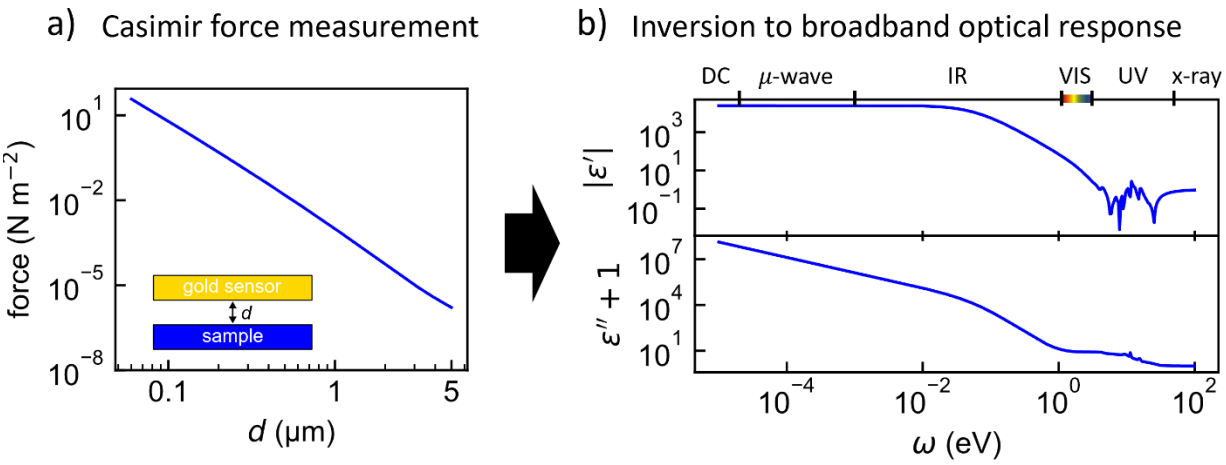

Figure 1: Conceptual framework for reconstructing broadband dielectric response from Casimir force measurements.

A5. LAMA effect for roughness-induced friction

Adrien Sutter[1,2], Lydéric Bocquet[2], Nikita Kavokine[1]

[1] The Quantum Plumbing Lab, EPFL, Lausanne, Switzerland
[2] Laboratoire de Physique de l'ENS, ENS-PSL, Paris, France

Abstract
We develop an analytical model to take into account phonon-related fluctuations into the derivation of roughness-induced friction at the solid-liquid interface. We show that friction results in the competition between two mechanisms: the Long-range Acoustic Mode Averaging, that reduces friction, and the Fluctuation-Induced mode coupling, that increases friction. In long enough carbon nanotubes, we show that the excitation of long-wavelength phonons leads to a significant LAMA contribution, explaining at least partially the unexpectedly low friction measured experimentally.

Keywords: Friction, phonons, fluctuating forces

A6. Perpetual cavities: a flow-cell for tunable optical microcavities

Oliver Svahn[1], Betül Kücüköz[1], Timur O. Shegai[1]

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Abstract

In colloidal systems, there exists an interplay of repulsive and attractive interparticle forces. This is famously formalised in the DLVO theory, considering contributions from electrostatic and dispersion forces (1-2). In recent works, these forces have been carefully tweaked to allow self-assembly of colloidal gold flakes into dimers with separation distances of 100-200 nanometres. A model system consisting of microscopic gold platelets in an aqueous cetyltrimethylammonium bromide solution (CTAB) has been extensively investigated (3-5), where the self-assembled dimers constitute optical Fabry-Pérot cavities. The local potential minimum is achieved through a combination of Casimir attraction and electrostatic repulsion due to adsorbed CTAB. The latter can be screened by addition of salt, making these colloidal cavities tuneable within the range of 100-200 nanometres. Among other things, this system has been used to determine the total interaction potential of single dimers (5). However, the methods employed in previous papers required the complete removal of solution during solvent exchange, thus rendering the tracking of a single cavity in different environments impossible. In this work, a flow-cell design has been developed to allow fluidic access to a chamber containing cavities. By patterning the bottom surface of the cell with gold seeds, dimers with colloidal flakes are effectively fixed in place, allowing the cell to be flushed with a new solvent without disrupting the cavities. This opens possibilities for confirming previous experimental results and constitutes a convenient platform for using the self-assembled cavities in a wider range of applications that require fluidic access.

Keywords: Casimir-Lifshitz, flow-cell, optical cavity

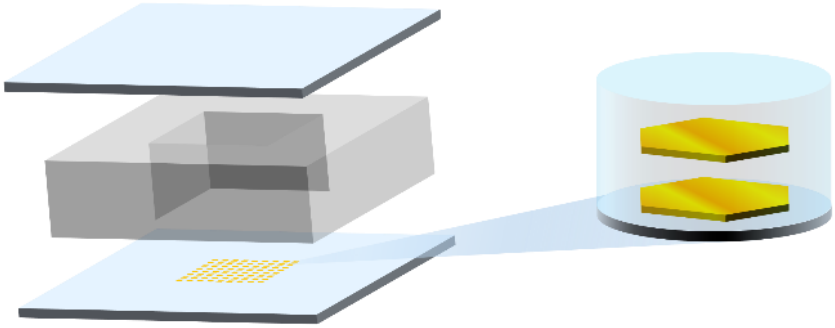

Figure 1: Schematic figure showing a cell with a PDMS cut-out (grey) sandwiched between microscope cover slips (blue). The bottom slide is patterned with gold seeds. To the side, an example cavity is shown.

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A7. Probing the dielectric properties of interfacial water near lipid membranes

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Abstract
The properties of water molecules surrounding biomolecules play a major role in determining their structure and functions.[1] In particular, the dielectric polarization properties of hydration layers forming near biological macromolecules are of major interest, as they govern electrostatic interactions between biological surfaces, [2] with major implications for membrane integrity, protein dynamics, and biochemical reaction kinetics.[3] Characterizing the dielectric properties of these hydration layers is therefore essential for understanding the fundamental mechanisms of biological function and interaction at the cellular level. However, experimental insights remain limited due to the lack of techniques with sufficient sensitivity and nanoscale resolution. In this work, we used advanced Atomic Force Microscopy (AFM) methods to measure the dielectric properties and atomic-scale arrangement of the lipid-water interface. Our approach builds on recent studies of our group in which the dielectric constant of water confined inside nanochannels made of van der Waals crystals was measured.[4] Here, we directly measured the dielectric properties of the interfacial water layers forming near lipid layers in aqueous environment and analyzed the results by using finite element numerical simulations. The new findings improve our understanding of the dielectric properties of water molecules structuring near soft biological surfaces.

Keywords: Dielectrics, Atomic Force Microscopy, Interfacial water, Lipid membranes

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A8. Probing dielectric polarization and conductivity of nanoconfined aqueous electrolytes

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Abstract
The structuring of ions and solvent molecules at the solid–liquid interface is a key factor in the formation of the electric double layer. Under strong confinement between surfaces, however, this structuring is expected to differ significantly from that at open interfaces, resulting in changes to the properties of the electric double layer. In particular, its polarization and electrodynamic properties are expected to differ substantially from those observed in bulk solutions and near surfaces. Despite their fundamental role in numerous physicochemical processes [1], these properties remain largely unexplored due to the difficulty of probing them directly at the molecular scale. In this work, we experimentally investigate the dielectric constant and conductivity of electrolytes confined within nanochannels fabricated from van der Waals nanochannels directly probing these properties using Scanning Dielectric Microscopy - an atomic force microscopy technique capable of probing local impedance. This study builds on recent work on the dielectric properties of nanoconfined water [2,3]. Our results improve our current understanding of the electrical properties of confined aqueous electrolytes, which are relevant to many technological applications as well as natural phenomena, and provide experimental benchmarks for theories describing electrostatic interactions between surfaces and molecules in electrolyte solutions.

Keywords: scanning dielectric microscopy, electrolytes, van der Waals materials, confinement

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