# CPP 41: Colloids and Complex Liquids I

Time: Thursday 9:30–13:00 Location: H40

**Invited Talk** CPP 41.1 Thu 9:30 H40

**Out-of-Equilibriumness of Light Activated Colloids** — •Jeremie Palacci, Stefano Sacanna, Asher Preska Steinberg, Adrian Vatchinsky, Kasey Hanson, David Pine, and Paul Chaikin — NYU, CSMR, USA

Self-propelled micro-particles are intrinsically out-of-equilibrium. This renders their physics far richer than that of passive colloids while relaxing some thermodynamical constraints and give rise to a wealth phenomena e.g. collective behavior, swarming...

I will present various properties of an assembly of synthetic active microparticles. I will notably introduce a new form of self-assembly originating from non-equilibrium driving forces. When activated by light, a set of new self-propelled particles spontaneously assemble into living crystals which behaves as " self-propelled colloidal carpets" steerable with an external magnetic field. We will show that this phenomenon is intrinsically out-of-equilibrium and originates in the competition between self-propulsion, particles collisions and attractive interactions. The applications and the use of this system for colloidal cargo transportation in microfluidic will also be discussed.

CPP 41.2 Thu 10:00 H40

**Individually tunable Micromachines driven by laser induced self propelled thermophoresis** — •Andreas Bregulla[1], Bian Qian[2], Haw Yang[2], and Frank Cichos[1] — [1]Universitiy of Leipzig, Germany — [2]Princeton University

Trapping and guiding individual micro- or nano-objects in solution by optical means is one important task for nanotechnology. Living cells have developed strategies to transport objects with the help of molecular motors. Thus combining active motion with optical control may deliver new pathways for micro and nanomanipulation. Here we present a new concept based on self-thermophoretic action. A particle which is capped by a thin metal layer is heated by an laser beam causing a temperature gradient along the particle surface. This temperature gradient leads to a directed thermophoretic propulsion of the particle. This directed motion, however, is randomized by rotational Brownian motion and just enhanced the diffusive motion on a large timescale. To overcome this randomizing a stochastic feedback mechanism can be developed, which employs the rotational Brownian motion to suppress their action. This method can be extended to the control of multiple individual particles on independent pathways and provides numerous new perspectives for nano-manipulations in liquids.

CPP 41.3 Thu 10:15 H40

**Active Brownian motion of asymmetric particles** — •Felix Kümmel[1], Ivo Buttinoni[1], Giovanni Volpe[3] und Clemens Bechinger[1,2] — [1]2. Physikalisches Institut, Universität Stuttgart, Germany — [2]Max-Plack-Institut für Intelligente Systeme, Stuttgart, Germany — [3]Bilkent University, Ankara, Turkey

Recently, various systems of active Brownian particles with simple geometries have been studied. Lately, a novel type of spherical active particles being propelled by the local demixing in a binary liquid has been experimentally realized [1]. Here, we investigate the active Brownian motion of asymmetric (L-shaped) particles. We observe an effective torque acting on the particles which results in a circular motion. We investigate this motion both under bulk conditions and close to walls where the torque leads either to the reflection or a sliding along the wall, depending on the direction of the torque. In addition, we investigate the self-propulsion of asymmetric particle under the influence of an external gravitational field. The resulting symmetry breaking causes a gravitactical behavior which strongly depends on the shape and the driving force of the swimmer.

[1] Volpe, G., I. Buttinoni, et al, Soft Matter 7, 8810 (2011)

**Invited Talk** CPP 41.4 Thu 10:30 H40

**Mesoscale Simulations of Active Colloids** — •Gerhard Gompper — Institute of Complex Systems, Forschungszentrum Juelich, Germany

Both in soft matter and in biology, there are numerous examples of swimmers and self-propelled particles. With a typical size in the range of a several micro-meters, both low-Reynolds-number hydrodynamics and thermal fluctuations are essential to determine their dynamics. Prominent examples are bacteria like E. coli which move forward by a rotational motion of their spiral-shaped flagella, and synthetic Janus colloids which catalyze a chemical reaction on their surface.

A powerful tool to study the non-equilibrium dynamics of active are mesoscale hydrodynamics simulation techniques, such as multi-particle collision dynamics (MPC), which describe the hydrodynamic behavior of a wide range of complex fluids very well [1].

We focus here on the cooperative behavior of active spherical and rod-like colloids [2], and on the dynamic properties of individual microswimmers near surfaces [3]. Active colloids display a strong surface excess in confined geometries and a pronounced clustering behavior in the bulk. The effects of self-propulsion, hydrodynamic interactions, microswimmer shape, and noise on these phenomena will be discussed.

[1] G. Gompper, T. Ihle, D.M. Kroll, R.G. Winkler, Adv. Polym. Sci. 221, 1 (2009).

[2] Y. Yang, V. Marceau, G. Gompper, Phys. Rev. E 82, 031904 (2010); I.O. Goetze & G. Gompper, Phys. Rev. E 82, 041921 (2010).

[3] J. Elgeti & G. Gompper, EPL 85, 38002 (2009).

CPP 41.5 Thu 11:00 H40

**Two-dimensional active Brownian motion of asymmetric microswimmers** — •Borge ten Hagen[1], Felix Kümmel[2], Raphael Wittkowski[1], Ivo Buttinoni[2], Giovanni Volpe[3], Clemens Bechinger[2,4], and Hartmut Löwen[1] — [1]Institut für Theoretische Physik II: Weiche Materie, Heinrich-Heine-Universität Düsseldorf — [2]2. Physikalisches Institut, Universität Stuttgart — [3]Department of Physics, Bilkent University, Cankaya, Ankara, Turkey — [4]Max-Planck-Institut für Intelligente Systeme, Stuttgart

We study the Brownian dynamics of asymmetric self-propelled particles in two dimensions. In our theoretical model based on the Langevin equations the propulsion mechanism is taken into account by means of an effective internal force. For asymmetric particles a non-central drive and translation-rotation coupling lead additionally to an effective intrinsic torque. When external forces are neglected, such particles move on a circular trajectory and the noise-averaged trajectory is predicted to be a logarithmic spiral. Under gravity several qualitatively different types of motion are found: Either a straight downward or upward motion (gravitaxis) occurs or the particle describes a periodic circling motion. Our theoretical description, which is very general and holds for arbitrarily shaped microswimmers, is verified in experiments with L-shaped model swimmers.

**15 min break**

CPP 41.6 Thu 11:30 H40

**Swimming trajectory of an active droplet** — •Max Schmitt and Holger Stark — Institut für Theoretische Physik, TU Berlin

In recent experiments a spherical microswimmer was realized by placing a micron-sized droplet of water and bromine into a surfactant rich oil medium [1]. This active droplet then started to swim in a random direction. However it did not swim in a straight line but rather changed its swimming direction on a timescale much shorter than that of thermal rotational diffusion.

The swimming motion arises due to a chemical reaction of the bromine with the surfactant monolayer at the droplet interface. The reaction product is a surfactant with a higher surface tension. As a consequence, local gradients in surface tension will lead to a fluid flow in the adjacent fluid inside and outside of the droplet. Due to this so-called Marangoni effect, the resting state of the droplet becomes unstable and the droplet starts to move. Simulations of a model in axisymmetric geometry, based on a free energy functional for the droplet interface, confirm the basic swimming motion of the droplet [2].

In a next step we want to explain the increased rotational diffusion relative to the simple thermal diffusion of a sphere. For this we include thermal fluctuations in the surfactant mixture at the interface and omit the axisymmetric constraint. The aim is to connect thermal fluctuations at the interface to the dynamics of the swimming direction of the whole droplet.

[1] Thutupalli S. *et al* 2011 *New J. Phys.* **13** 073021

[2] Schmitt M. and Stark H. 2012 *arXiv* 1210.2560

CPP 41.7 Thu 11:45 H40

**Collective dynamics of spherical microswimmers in a quasi-**

**2D geometry** — •Andreas Zöttl and Holger Stark — TU Berlin

Microorganisms like bacteria, algae or spermatozoa typically move in an aqueous environment where they interact via hydrodynamic flow fields and confining boundaries. Recent experiments studied the collective motion in dense bacterial suspensions where swarming and large-scale turbulence emerged. Moreover, spherical artificial microswimmers, so-called squirmers, have been constructed and studied in a quasi-2D geometry.

First we show that a microswimmer moving in Poiseuille flow in a narrow channel performs van der Pol-like oscillations. Then we present a numerical study of the collective dynamics of squirmers confined in quasi-2D between two parallel walls. Because of their spherical shape the reorientation of squirmers is solely due to noise and hydrodynamic interactions via induced flow fields. This is in contrast to elongated swimmers like bacteria which locally align due to steric interactions.

We study the collective motion of pushers, pullers and potential swimmers at different densities. At small densities the squirmers are oriented parallel to the walls and pairwise collisions determine the reorientation rate. In dense suspensions rotational diffusion is greatly enhanced and pushers, in particular, tend to orient perpendicular to the walls. This effects the dynamics of the emerging clusters. In very dense suspensions we observe active jamming and long-lived ordered structures. The critical area fractions for the formation of crystalline phases is different for pushers, pullers and potential swimmers.

**Invited Talk** CPP 41.8 Thu 12:00 H40

**Orientational Order and Packings of Non-Spherical Particles** — •Klaus Mecke, Rene Wittmann, Sebastian Kapfer, and Gerd Schröder-Turk — Institut für Theoretische Physik, FAU, 91058 Erlangen, Germany

Since the seminal work by Y. Rosenfeld in 1989 for fluids of hard spheres a density functional theory is much sought after, which can describe quantitatively hard colloidal particles with arbitrary shapes. A new functional, which is based on fundamental mixed measures known from translative integral geometry, captures nematic and smectic phases correctly and can be used to determine surface tensions and Frank elastic constants.

The bond-orientational order parameter introduced in 1983 by Steinhardt et al. became a standard tool for local structure characterization in colloidal systems, with applications on jamming, crystallization or cluster formation. Unortunately, the definition of the particle neighborhood significantly affects their interpretation for disordered systems. Mixed measures as well as the related Minkowski tensors can be used to remedy the deficiencies and to characterize local orientational order of non-spherical particles in fluid phases, liquid crystals and also in disordered packings.

CPP 41.9 Thu 12:30 H40

**Density functional theory for liquid crystals** — •René Wittmann and Klaus Mecke — Institut für Theoretische Physik, Friedrich-Alexander-Universität Erlangen-Nürnberg, Staudtstraße 7, 91058 Erlangen, Germany

Fluids of hard spherocylinders exhibit rich phase behavior including isotropic, nematic and smectic phases. The Fundamental Measure Theory for arbitrarily shaped hard particles [1] is applied to this model system within the so-called $\zeta$-approximation.

The spatial homogeneous phases as well as perfectly aligned systems can be treated analytically. Systematically adding higher order terms improves upon the original $\zeta$-correction but remains computationally inefficient for inhomogeneous phases.

We present new results for the phase behavior, the isotropic-nematic interface and the Frank elastic coefficients for the nematic phase. A qualitative comparision with Monte-Carlo simulations confirms the DFT results and for the isotropic-nematic transition we recover the exact Onsager-limit.

[1] H. Hansen-Goos and K. Mecke, Phys. Rev. Lett. **102**, 018302 (2009).

CPP 41.10 Thu 12:45 H40

**Phase behavior of plate-like block copolymer single crystal suspensions** — Chunbo Jiang[1], Haiying Huang[1], Cungui Ma[1], Tianbai He[1], and •Fajun Zhang[2] — [1]State Key Laboratory of Polymer Physics and Chemistry, CIAC, CAS, China — [2]Institut für Angewandte Physik, Universität Tübingen

We have studied the influence of particle size and tunable lateral interaction on the isotropic-nematic phase transition of a plate-like colloidal system. The particles are single crystals of a block copolymer PS-b-PLLA prepared using a self-seeding procedure in solutions [1]. These lozenge shape crystals have uniform thickness and narrowly distributed lateral size. The phase behavior is characterized under crossed-polarizers for all systems with size ranging from 500 to 4000 nm. It is surprising to see that the I-N transition occurs at a much lower volume fraction than the theoretical predicted value. However, if adding ethanol into the solution the I-N transition is significantly suppressed. These results demonstrate the existence of a lateral attraction between crystals and it is most likely due to the polar interaction between the crystalline PLLA. Because of the sandwich structure of the crystals, the confinement by the amorphous PS layers renders the attraction highly orientation dependence. In this way, larger plate-sheets are formed via lateral attraction and give a much lower critical volume fraction. To further demonstrate this highly orientational attraction, we have further prepared a composite single crystal with a PLLA homopolymer. Indeed, the resulting liquid crystalline phases show much less horizontal ordering. [1] Jiang C. et al. Langmuir 2011, 27, 4351