WWU MÜNSTER

Center for Nonlinear Science

Advanced School

From Complex Fluids to Living Matter

24.–28. September 2018

living.knowledge

Contact:

Prof. U. Thiele
Institut für Theoretische Physik
WWU Münster
Wilhelm-Klemm-Straße 9
48149 Münster
Tel.: +49 251 83 34939
Fax: +49 251 83 36328
Arndt.u.thiele@uni-muenster.de

Dr. O. Kamps
Center for Nonlinear Science
WWU Münster
Correnssstraße 2
48149 Münster
Tel.: +49 251 83 33515
Fax: +49 251 83 33513
okamp@uni-muenster.de

LOCATION

The workshop takes place in room 304 of the

Institut für Theoretische Physik
University of Münster
Wilhelm-Klemm-Straße 9
48149 Münster

FROM COMPLEX FLUIDS TO LIVING MATTER

The Advanced School takes place in Münster, Germany, 24-27th September 2018 and is organised by the International Doctoral School âActive living fluidsâ and the Center for Nonlinear Science, WWU Münster (CeNoS). It combines long tutorial lectures with shorter talks and is aimed at advanced Master students, PhD candidates and other researchers interested in the field. Experimental and theoretical approaches to a variety of subjects are introduced ranging from the interfaced-dominated dynamics of phase transitions in complex fluids and soft matter systems to biofluiddynamics (e.g., blood flow) or the dynamics of bacterial colonies and tissues.

This school will present a broad perspective on the different phenomena. Important phenomena are introduced in presentations of important experimental examples. Theoretical descriptions range from microscopic stochastic discrete to meso- and macroscopic deterministic continuum approaches and are related to open basic questions in our understanding of non-equilibrium phenomena. Most presentations contain a significant introductory component which will, in particular, be very profitable for advanced students in the field. The schedule reserves ample time for discussions that will hopefully connect the different ideas and approaches even more closely.

MONDAY, 24.09.2018

PROGRAM

12.30	Registration	
13.45	Opening	**C. Wagner, U. Thiele**
14.00	The physics of active motion in biological systems	**T. Betz**
15.30	Coffee	
16.00	Modeling the dynamics of active soft matter	**R. Wittkowski**
17.30	Welcome buffet and poster (open end)	

T. Betz Universität Münster

The physics of active motion in biological systems

Living biological systems are continuously reorganizing their structure to perform their function. The mechanical activity plays here an important role, as the constant generation of forces drives fluctuations as well as controlled motion of intracellular particles, membranes and even whole cells. From a physical point of view, this active motion drives the system far away from thermodynamic equilibrium, which can be measured as a violation of equilibrium quantities such as the fluctuation dissipation theorem. Quantifying the out-of-equilibrium components provides the possibility to model the active molecular processes. We measure the energy and the forces actively applied and model these with an active Langevin approach. On the scale of multicellular systems and tissue we are interested in collective motion which is still poorly understood. Here we use 3D tracking and hydrodynamic models to quantify and understand morphological changes ranging from tumor invasion up to embryonal development.

R. Wittkowski Universität Münster

Modeling the dynamics of active soft matter

Active soft matter contains constituents that are able to move autonomously. Through the energy dissipation of these "active" constituents, active soft matter is intrinsically out of thermodynamic equilibrium. As a consequence, many of the standard laws and methods from thermodynamics can typically not be applied to active soft matter. Instead, new theoretical methods that are applicable far from equilibrium are required. This lecture addresses multiscale methods that allow to derive models for active-soft-matter systems. The focus of the lecture is on field-theoretical methods for modeling the collective dynamics of suspensions of active colloidal particles.

A. Förtsch Universität Bayreuth

Poster: Oscillatory phase separation in active particle systems

We introduce a model with two types of interacting active particles A and B. We assume A-A attraction, A-B attraction and B-B repulsion. The continuum approximation corresponds to two chemotactically interacting species. This continuum model shows an oscillatory instability. Since the two particle types are conserved, this oscillatory instability leads to oscillatory phase separation. Particle simulations lead to the same scenario. Above the oscillatory onset of phase separation, we find traveling clusters in simulations

TUESDAY, 25.09.2018

PROGRAM

9.00	Pattern formation in active matter: Bacterial swarming and microswimmer suspensions	**M. Bär**
10.30	Coffee	
11.00	Passive swimming of soft particles in oscillatory Poiseuille flow	**W. Schmidt**
11.30	Extraction of bacteria-motion statistics	**O. Köhn**
12.00	Lunch	
14.00	3D tomography of blood flow	**C. Wagner**
15.30	Coffee	
16.00	Board meeting	
17.00	End	

M. Bär Physikalisch-Technische Bundesanstalt Berlin

Pattern formation in active matter: Bacterial swarming and microswimmer suspensions

Active matter contain a large number of active agents which consume energy in order to move. Examples include bacterial swarms and suspensions of microswimmers. The talk surveys two representative examples for spatiotemporal self-organisation in active fluids: (i) formation of polar clusters and nematic bands [1-5] in the swarming of bacteria gliding on a surface and (ii) the so called *mesoscale turbulence* in dense suspensions of swimming bacteria. We show that many aspects of the swarming dynamics of bacteria on a surface are reproduced in agent-based [1-4] and continuum models of self-propelled rods [5]. Mesoscale turbulence in bacterial suspensions [6] is qualitatively modelled by agent-based models with self-propelled particles with competing alignment interactions [7, 8]. In a more quantitative approach bacterial turbulence is found to be caused by the interplay of active motion, local alignment of swimmers and long-range hydrodynamic interactions with the help of a continuum model derived from the dynamics of individual swimmers [9, 10].

[1] F. Peruani, A. Deutsch and M. Bär. Nonequilibrium clustering of self-propelled rods. Phys. Rev. E 74, 030904, 2006.

[2] F. Ginelli, F. Peruani, M. Bär and H. Chaté. Large-scale collective properties of self-propelled rods.Phys. Rev. Lett. 104, 184502, 2010.

[3] F. Peruani, J. Starruß, V. Jakovljevic, L. SÃžgaard-Andersen, A. Deutsch and M. Bär. Collective Motion and Nonequilibrium Cluster Formation in Colonies of Gliding Bacteria. Phys. Rev. Lett. 108, 098102, 2012.

[4] F. Peruani and M. Bär. A kinetic model and scaling properties of non-equilibrium clustering of self-propelled particles. New J. Phys. 15, 065009, 2013.

[5] R. Großmann, F. Peruani and M. Bär. Mesoscale pattern formation of self-propelled rodswith velocity reversal. Phys. Rev. E 94, 050602, 2016.

[6] J. Dunkel, S. Heidenreich, K. Drescher, H. H. Wensink, M. Bär and R. E. Goldstein. Fluid Dynamics of Bacterial Turbulence. Phys. Rev. Lett., 110 228102, 2013.

[7] R. Großmann, P. Romanczuk, M. Bär and L. Schimansky-Geier. Vortex arrays and mesoscale turbulence of self-propelled particles. Phys. Rev. Lett. 113, 258104, 2014.

[8] R. Großmann, P. Romanczuk, M. Bär and L. Schimansky-Geier. Pattern formation in active particle systems due to competing alignment interactions. Eur. Phys. J - Special Topics 224, 1325-1347, 2015.
[9] S. Heidenreich, J. Dunkel, H. Klapp and M. Bär. Hydrodynamic length-scale selection in microswimmer suspensions. Phys. Rev. E 94, 020601, 2016.
[10] H. Reinken, S. H. L. Klapp, M. Bär and S. Heidenreich. Derivation of a hydrodynamic theory for mesoscale dynamics in microswimmer suspensions. Phys. Rev. E 97, 022613, 2018.

W. Schmidt Universität Bayreuth

Passive swimming of soft particles in oscillatory Poiseuille flow

What is the dynamical behavior of soft particles in oscillatory (pulsating) Poiseuille ow at low Reynolds number? By investigating the overdamped motion of bead-spring models for a triangle, 2D ring polymers, 3D capsules, and red blood cells, we predict particle actuation in the case of vanishing mean flow. This effect is generic as it does not depend on the model. Asymmetric, Janus like particles propagate in a symmetric ow. Symmetric particles swim for non-symmetric ow oscillations (non equal half periods). The mean actuation (swim) velocity of a particle is caused by its varying shape in both half periods. Since the actuation steps depend also on the size and the elasticity of soft particles, this novel actuation (passive swimming) mechanism is also appropriate for particle sorting.

O. Köhn Universität des Saarlandes

Extraction of bacteria-motion statistics

Bacteria tend to swim in liquids in absence of food facilitated by creation of flagella. The trajectories are determined by slightly curved lines (running states) and randomly interrupted by short intervals with strong direction changes (tumbling state)[1]. This behavior seems to be efficient in finding food in unknown environments. We assume an intrinsic randomness in the running states as well in the appearance of the tumbling intervals [1]. Furthermore in real experiments the extracted positions are influenced by a detection noise. Estimating the stochastic trajectory properties requires the distinction between bacteria intrinsic randomness and the measurement noise. From the engineers it is known that the Kalman-filter algorithm provides this in an optimal way [2]. We adapted and implemented this filter for simulated as well as measured bacteria trajectories.

[1] Enhancing bacterial motility and search efficiency by genetic manipulation of flagellar number; Javad Najafi, M. Reza Shaebani, Thomas John, Florian Altegoer, Gert Bange Christian Wagner; submitted to PNAS
[2] Forecasting, structural time series models and the Kalman filter; Andrew C. Harvey; 1989; Cambridge University Press

C. Wagner Universität des Saarlandes

3D tomography of blood flows

Red blood cells (RBCs) are very soft objects that can pass capillaries smaller than the cellâs diameter. Due to their high deformability, they couple strongly with the flow and can adopt many different shapes. For their quantitative characterization we developed a new confocal 3D imaging technique for fluorescent stained RBCs. Our approach allows us to recover the full 3D representation of moving RBCs under conditions prevailing in the micro-vasculature. As a key feature, we employ a micro-fluidic channel which is tilted by a small angle with respect to the objective. Image slices are then assembled to recover the volumetric representation of individual cells. We found two equilibrium cell shapes under certain flow condition: the so called ’slipper’ and the ’croissant’ shape. Numerical simulations are in good agreement with experimental observations [1]. In addition, high throughput data of classical 2-D microscopy combined with an adaptive neural network allow us to obtain the full phase diagram of red blood cell shapes as a function of the flow rate [2]. In larger channels, we use the confocal technique to characterize the margination of single rigidified RBCs in a suspension of healthy RBCs. Margination of e.g. white blood cells or platelets at the vessel walls is a haemodynamic key mechanism of our immune system. Our confocal observation technique allows us to characterize the distribution of hard vs. soft cells in full time and space resolution for the first time. Again numerical simulations are in good agreement although some quantitative differences remain that need further investigations.

[1] S. Quint. et al. (2017). Applied Physics Letters, 111(10), 103701.
[2] A. Kihm et al. (2018). PLOS Computational Biology

WEDNESDAY, 26.09.2018

PROGRAM

9.00	Pattern formation: wavelength selection, coarsening and front propagation	**C. Misbah**
10.30	Coffee	
11.00	Amoeboid swimming in elastic channels	**S. Dalal**
11.30	Inertia driven swimming of soft microparticles in oscillatory flows	**M. Laumann**
12.00	Lunch	
14.00	Derivation of continuous equations for an isotropic active elastic network	**K. John**
15.30	Coffee	
16.30	Guided city tour	
19.00	Conference Dinner (open end)	

C. Misbah Université Grenoble Alpes

Pattern formation: wavelength selection, coarsening and front propagation

General questions on pattern formation will be discussed. The talk will be focused first on the longstanding puzzle of wavelength selection. Indeed, unlike equilibrium systems for which an optimization principle exist (e.g. maximum entropy for an inoculated system), there is no such principle in non equilibrium systems. Attempts to resolve this issues will be presented. One particular situation in non equilibrium systems is the fact that some systems exhibit (i) coarsening (increase of wavelength with time), (ii) no coarsening, I which the wavelength is fixed in time and (iii) interrupted coarsening (increase of wavelength with time until a crayon size and then the system ceases to coarsen. We will see that for some classes of nonlinear equations it is possible to show which scenario prevail without solving time-dependent equations. Finally, a discussion will be devoted to front propagation. Indeed, patterns can take place locally in space, and then invade the whole system via front propagation. We will see one major dilemma of front propagation in none-quilibruim systems in which the front velocity can be selected (from an infinite set of solutions) from a subtle mechanism. Example will be borrowed from physics, chemistry, biology, including living fluids and active matter.

S. Dalal Université Grenoble Alpes

Amoeboid swimming in elastic channels

The microorganisms such as Eutreptielle Gymnastica and eukaryotic cells such as neutrophils, leukocytes propel by using shape deformation based swimming strategy. We used simplified shape deformation based active force model to mimic such amoeboid swimming behaviour. The microswimmers come in contact with variety of surfaces and exhibit distinct swimming nature. The microorganisms such as E. Coli exhibit different swimming trajectories near rigid and deformable surfaces. Many biological activities such as spermatozoa motility through mucus filled female reproductive tract, water snails crawling upside down beneath the free surface involve interaction between microswimmer and deformable surfaces. Considering importance of such interaction, we numerically investigate motion of microswimmer through the elastic channel and study the effects of wall stiffness on swimming dynamics. The amoeboid swimmer in presence of elastic surface is found to exhibit behaviour in qualitative agreement with certain cancerous cells. Thus this study may provide some insights into growth and spreading of these cancer cells.

M. Laumann Universität Bayreuth

Inertia driven swimming of soft microparticles in oscillatory flows

Biological and bioinspired microswimmers move via active shape changes. Great progress has been made in understanding and control of active locomotion of microswimmers. However, actuation of microparticles caused by a time-dependent uid motion is less well explored. Recently it was demonstrated that an asymmetric, deformable micro-particle can be actuated by an oscillating ow via inertia effects (vanishing mean flow) [1]. Here we give an explanation of this passive swimming effect in terms of an elemantary bead-spring tetrahedron. We demonstrate this passive swimming effect also for a 3d capsule. We determine the dependence of the mean actuation velocity of the particle in terms of the flow and the particle parameters which my pave the way for designing artificial swimmers in oscillatory flows.

[1] I. Jo and Y. Huang and W. Zimmermann and E. Kanso. Passive swimming in viscous oscillatory flows. Phys. Rev. E, Vol. 94, Iss. 6 - 2016.

K. John Université Grenoble Alpes

Derivation of continuous equations for an isotropic active elastic network

The standard active gel theory postulates phenomenological continuous equations for the density, stress, and local orientation fields on the basis of symmetry and linear irreversible thermodynamics arguments [1]. In most cases, the gels considered behave as liquids on long time scales, but 'solid' active gels, which do not flow at long time under an externally applied shear, have also been studied [2]. In this work, we derive the large-scale continuous description of an isotropic elastic network in the presence of force dipoles and momenta (a crude modeling of an actin network with molecular motors) which generate an active stress. The main results of this explicit coarse-graining procedure are two-fold. First, the derivation yields non-linear terms able to saturate the instability reported in linear active gel theory. Second, activity (i.e., the strength of force dipoles and momenta) not only generates new 'active' terms with respect to the passive case, but also 'renormalizes' the passive elastic properties of the medium. This change of the elastic properties leads for example to a shear instability for extensile force dipoles, while standard active gel theory yields an instability for contractile dipoles [2].

[1] K. Kruse, J.F. Joanny, F. Jülicher, J. Prost, and K. Sekimoto, Eur. Phys. J. E 16, 5 (2005).
[2] S. Banerjee and M.C. Marchetti, Soft Matter 7, 463 (2011).

THURSDAY, 27.09.2018

PROGRAM

9.00	Pattern Formation: Size matters, heterogeneities, conservation contraints	**W. Zimmermann**
10.30	Coffee	
11.00	Resting and Traveling Localized States in an Active Phase-Field-Crystal Model	**L. Ophaus**
11.30	Modelling of front instabilities in surfactant-driven spreading of bacterial colonies	**S. Trinschek**
12.00	Lunch	
14.00	Flowing Active Suspensions: Plankton as a model active particle	**S. Rafai**
15.30	Coffee	
16.00	Spatio-temporal control of self-organized structures in dynamic self-assembled systems self-assembled systems	**S. Gurevich**
16.30	Introduction to continuation with *pde2path*	**T. Frohoff-Hülsmann**
17.00	Closing	
17.30	End	

W. Zimmermann Universität Bayreuth

Pattern Formation: Size matters, heterogeneities, conservation contraints.

Patterns are ubiquitous in nature and materials. In this talk I will address shortly three issues. How a finite size may influence the behavior of patterns or even changes the type of a pattern [1,2]? How, will heterogeneities act on patterns [3,4,5]? A number of demixing phenomena show âactive phase separationâ, which is at leading order described by the classical Cahn-Hilliard model [6]. What are further possible effects of conservation constraints?

[1] L. Rapp, F. Bergmann and W. Zimmermann, Pattern orientation in finite domains without boundaries, EPL 113, 28006 (2016).
[2] F. Bergmann, L. Rapp, und W. Zimmermann, Size matters for nonlinear (protein) wave patterns, New J. Phys. (Fast Track), 072001 (2018).
[3] B. Kaoui, A. Guckenberger, A. Krekhov, F. Ziebert, W. Zimmermann, Coexistence of Stable Branched Patterns in Anisotropic Inhomogeneous Systems, New J. Phys. 17, 103015 (2015).
[4] B. A. Glatz, M. Tebbe, B. Kaoui, R. Aichele, C. Kuttner, A. E. Schedl, H.-W. Schmidt, W. Zimmermann, A. Fery, Hierarchical Line-Defect Patterns in Wrinkled Surfaces, Soft matter 11, 3332 (2015).
[5] R. Aichele, B. Kaoui, F. Ziebert, and W. Zimmermann, Branched wrinkles in inhomogeneous films on substrate systems, (submitted).
[6] F. Bergmann, L. Rapp, and W. Zimmermann, Active phase separation: A universal approach, Phys. Rev. E 98, 020603(R) (2018).

L. Ophaus Universität Münster

Resting and Traveling Localized States in an Active Phase-Field-Crystal Model

The conserved Swift-Hohenberg equation (or Phase-Field-Crystal [PFC] model) provides a simple microscopic description of the thermodynamic transition between fluid and crystalline states. Combining it with elements of the Toner-Tu theory for self-propelled particles Menzel and Löwen [Phys. Rev. Lett. 110, 055702 (2013)] obtained a model for crystallization (swarm formation) in active systems. Here, we study the occurrence of resting and traveling localized states, i.e., crystalline clusters, within the resulting active PFC model. Based on linear stability analyses and numerical continuation of the fully nonlinear states, we present a detailed analysis of the bifurcation structure of periodic and localized, resting and traveling states in a one-dimensional active PFC model. This allows us, for instance, to explore how the slanted homoclinic snaking of steady localized states found for the passive PFC model is amended by activity. A particular focus lies on the onset of motion, where we show that it occurs either through a drift-pitchfork or a drift-transcritical bifurcation. A corresponding general analytical criterion is derived.

S. Trinschek Universität Münster

Modelling of front instabilities in surfactant-driven spreading of bacterial colonies

The spreading of bacterial colonies at solid air interfaces hinges on physical processes connected to the properties of the involved interfaces. The production of surfactant molecules by the bacteria is one strategy that allows the bacterial colony to efficiently expand over a substrate. These surfactant molecules affect the surface tension which results in an increased wettability as discussed in [1] as well as in outward-pointing Marangoni fluxes that promote spreading. These fluxes may cause an instability of the circular colony shape and the subsequent formation of fingers. In this work, we study the front instability of bacterial colonies at solid-air interfaces induced by surfactant production in the framework of a passive hydrodynamic thin-film model which is extended by bioactive terms. We show that the interplay between wettability and Marangoni fluxes determines the spreading dynamics and decides whether the colony can expand over the substrate. We observe four different types of spreading behaviour, namely, arrested and continuous spreading of circular colonies, slightly modulated front lines and the formation of pronounced fingers.

[1] S. Trinschek et al., PRL 119, 078003 (2017)

S. Rafai Université Grenoble Alpes

Flowing Active Suspensions: Plankton as a model active particle

Suspensions of motile living organisms represent a non-equilibrium system of condensed matter of great interest from a fundamental point of view as well as for industrial applications. These are suspensions composed of autonomous units - active particles - capable of converting stored energy into motion. The interactions between the active particles and the liquid in which they swim give rise to mechanical constraints and a large-scale collective movement that have recently attracted a great deal of interest in the physical and mechanical communities. From the industrial point of view, microalgae are used in many applications ranging from the food industry to the development of new generations of biofuels. The biggest challenges in all these applications are the processes of separation, filtration and concentration of microalgae. There is therefore a real need for a better understanding of the flow of active material in order to ensure optimal control of these systems.

Our recent work on microalgae suspensions will be presented. The micro alga Chlamydomonas Reinhardtii uses its two anterior flagella to propel itself into aqueous media. It then produces a random walk with persistence that can be characterised quantitatively by analysing the trajectories produced. Moreover, in the presence of a light stimulus, it biases its trajectory to direct it towards the light: this phenomenon is called phototaxis. By coupling experiments and modeling, we propose to extract from the hydrodynamic characteristics of this microalga the generic properties of microswimmer suspensions. How does the swimming of an active particle couple with a flow? How is the dispersion of active particles affected by hydrodynamic interactions?

References

[1] Matthieu Martin, Alexandre Barzyk, Eric Bertin, Philippe Peyla, Salima Rafai. Photofocusing: Light and flow of phototactic microswimmer suspension. Physical Review E , 2016, 93 (5), pp.051101(R).
[2] Xabel Garcia, Salima Rafai, Philippe Peyla. Light Control of the Flow of Phototactic Microswimmer Suspensions. Physical Review Letters, 2013, 110, pp.138106.
[3] Salima Rafai, Levan Jibuti, Philippe Peyla. Effective Viscosity of Microswimmer Suspensions. Physical Review Letters, 2010, 104, pp.98102.

S. Gurevich Universität Münster

Spatio-temporal control of self-organized structures in dynamic self-assembled systems self-assembled systems

Self-organization or dynamic self-assembly is a mechanism responsible for the formation of complex structures through multiple interactions among the microscopic components of the system. We are interested in the formation of regular stripe patterns during the transfer of surfactant monolayers from water surfaces onto moving solid substrates by means of a generalized Cahn-Hilliard equation. A combination of numerical simulations and continuation methods is employed to investigate stationary and time-periodic solutions of the model. Further, the influence of the spatio-temporal forcing on the patterning process is discussed. We show that the occurring locking effects enable a control mechanism via properties of the forcing and facilitate the production of patterns with a broader range of features. In two dimensions, the production of a variety of complex patterns can be achieved through the competition of intrinsic properties of the pattern forming system and the external forcing.

T. Frohoff-Hülsmann Universität Münster

Introduction to continuation with *pde2path*

Numerical continuation methods provide a powerful tool to approximate the solution space of PDEs (partial differential equations). One can track families of equilibria, calculate their stability and detect and follow bifurcations. This numerical analysis of PDEs yield an understanding of the underlying physical systems and their behaviour with parameter changes. In this talk we will introduce the basic ideas of (pseudo)arclength continuation and recall the theory of weak solutions and its application to the FEM (finite element method). *pde2path* is a Matlab continuation package, which will then be used in the main part of the talk. Some examples of different equation classes will be examined for one and two spatial dimensions. Thereby, we will discuss the benefits of *pde2path* such as mesh adaption, the possible usage of different boundary condition or space geometries and the implementation of constraints.

NOTES

NOTES

THE CENTER FOR NONLINEAR SCIENCE

The study of nonlinear, complex systems is one of the most exciting and fastest growing branches in science nowadays. Understanding the mechanisms governing cooperative, emergent phenomena in complex systems is considered as one of the most important challenges in science, because it is a highly interdisciplinary field that has important applications in fields ranging from physics, mathematics, chemistry, engineering and computer science to life sciences, sociology and finances.

The Center for Nonlinear Science (CeNoS) was founded to foster research and education in the field of nonlinear science and to strengthen the dialogue between different scientific disciplines at the University of Münster. For further information visit:

www.uni-muenster.de/cenos