BP 11: Posters: Cytoskeleton

Time: Tuesday 9:30–12:30 Location: P1

BP 11.1 Tue 9:30 P1

Time-resolved study of vimentin aggregation mediated by multivalent cations — •Christian Dammann and Sarah Köster — Institute for X-Ray Physics, Georg-August-Universität Göttingen, Friedrich-Hund-Platz 1, 37077 Göttingen, Germany

Besides actin filaments and microtubules, intermediate filaments (IFs) are a major component of the cytoskeleton, forming networks and bundles in the cell. Attractive interactions between purified negatively charged IFs can be mediated by small cations and the understanding of these interactions increases the knowledge of the cytoskeleton on a fundamental level. Here, we directly image the attractive interaction of vimentin IFs in the presence of multivalent cations using time-lapse fluorescence imaging. The dynamics of this process are followed in a drop-based microfluidic device that allows for rapid imaging shortly after the first protein-cation contact. Given a necessary threshold cation concentration, we find that the aggregation process takes place on the order of a few minutes. During this process the initially freely fluctuating filaments form highly compacted networks. We interpret our findings with regard to competitive binding of mono- and multivalent cations onto the filaments and find an explanation for the observed attraction mechanism. Our result emphasizes the important role of electrostatics for cytoskeletal proteins. The findings are likely to be representative for the class of vimentin-like IFs.

BP 11.2 Tue 9:30 P1

Entropic contraction of actin networks — •Carsten Schuldt, Tom Golde, Jörg Schnauss, Martin Glaser, and Josef A. Käs — Universität Leipzig , Institut für Experimentelle Physik I, Physik der weichen Materie, Linnéstr. 5, 04103 Leipzig, Germany

Retraction at the rear of a cell is a fundamental part of its migration process. This contraction can be accomplished by actin-myosin interaction. However, myosin knock-out cells have been shown to be still capable of migration. Alternatively, the depolymerization of the cytoskeleton was proposed to cause contractile forces only by a gain in entropy in the absence of molecular motors. This concept has been demonstrated on polymer mesh-works of nematode's major sperm protein.

We study the depolymerization of actin networks. In particular, the mesoscopic details and the forces associated with this process are of interest. We employ a micro-rheology approach in conjunction with light induced softening of actin networks [1] to measure both softening and contraction of the depolymerizing mesh-work.

[1] Golde *et al.* 2013. PRE 88:044601

BP 11.3 Tue 9:30 P1

Dynamics of active actin network contraction — •Dominic Jourdain[1], Anne Bernheim[2], and Karsten Kruse[1] — [1]Universität des Saarlandes, Germany — [2]Ben Gurion University, Israel

Recent in vitro experiments on actin filaments together with myosin motors reveal characteristic contraction patterns. The contraction speed increases linearly at first, before it decays exponentially. For asymmetric initial x-y-aspect-ratios, the contraction seems to follow this asymmetry. Using a continuous nonlinear Neo-Hookian elastic model for the filaments with a density dependent extra term to take the motor activity into account, we are able to qualitatively reproduce the asymmetric contraction and the contraction speed curves. To this end, a triangular finite element simulation is used.

BP 11.4 Tue 9:30 P1

Visco-elastic properties of artificial biopolymer networks — •Matthias Koch, Dominic Ruh, and Alexander Rohrbach — Lab for Bio- and Nano-Photonics, University of Freiburg, Georges-Koehler-Allee 102, 79110 Freiburg, Germany

Microtubules (MT) are biopolymers which self-organize over a large spatial and temporal scale in living cells as a response to a variety of external stimuli. Most of the highly complex intracellular processes like cell-division or mechanotransduction are based on MT networks. The mechanical properties of single biopolymers like actin filaments or microtubules have already been studied in a wide context. However, the role of the meshwork geometry on the transport of mechanical momentum in a two dimensional MT network has not been studied so far.

Optical tweezers allow generating an array of anchor points for artificial polymer networks consisting of fluorescently labelled MT filaments attached to optically trapped 1μm spheres. We use multiple time-multiplexed optical traps which are displaced at rates up to 50kHz for both 3D force generation and measurements. The positions of the trapped particles can be evaluated using back focal plane interferometry, allowing resolving momentum propagation through the network. This configuration allows probing the visco-elastic properties of biopolymers in synthesized networks in a bottom-up approach and might reveal deeper insights in their complex interaction as part of the cytoskeleton. Results from first experiments with fluorescently labelled MT filaments attached to optically trapped 1μm spheres are presented.

BP 11.5 Tue 9:30 P1

On the homogeneity of in vitro assembled keratin 8/18 networks — •Tobias Neckernuss[1], Katinka Mertens[1], Ines Martin[1], Tobias Paust[1], Michael Beil[2], Raphael Blumenfeld[3], and Othmar Marti[1] — [1]Department of Experimental Physics, Ulm University, D-89069 Ulm — [2]Clinic of Internal Medicine I, Ulm University, D-89069 — [3]Department of Earth Science & Engineering, Imperial College London, GB-London SW7 2BP

The cytoskeleton of epithelial cells consists of three types of filament systems: microtubules, intermediate filaments IFs and actin filaments. In our work, we have a closer look on in vitro assembled intermediate filaments consisting of keratin 8/18 and $MgCl_2$, serving as a crosslinker. With an optical trap we are able to determine mechanical properties of the network by trapping and exciting an embedded polystyrene bead which motion is transferred via the network to response beads in the surrounding. Correlating the motion of the excited beads with the ones of the response beads allows us to determine the homogeneity of the network. The setup for such a multibead microrheology measurement is presented as well as the evaluation methods. Furthermore the linearity of the networks response is tested with single bead measurements.

BP 11.6 Tue 9:30 P1

thermal fluctuation of branched biopolymers and resulting entropic force — •mohammadhosein razbin[1,2], panayotis benetatos[3], martin falcke[4], and annette zippelius[1,2] — [1]Institute for Theoretical Physics, Georg-August University , Friedrich-Hund-Platz 1, 37077 Goettingen, Germany — [2]Max Planck Institute for Dynamics and Self-Organization, Am Fassberg 17, 37077, Goettingen, Germany — [3]Department of Physics, Kyungpook National University, South Korea — [4]Mathematical Cell Physiology, Max-Delbrück-Center for Molecular Medicine, Robert-Rössle-Straße 10, D-13092 Berlin, Germany

We consider branched structures of biopolymers, such as actin polymerized by Arp2/3. The polymers are modeled as weakly bending chains, which are grafted at one end and form branches at a given angle. we compute the thermal fluctuation of the endpoints and the resulting entropic forces on a flat membrane, restricting the fluctuations of the endpoints. The entropic forces are shown to depend sensitively not only on the persistence length but also on the geometry of the structure.

BP 11.7 Tue 9:30 P1

Impact of cell-sized confinement on the dynamics of actin polymerization — •Zoe Swank, Siddharth Deshpande, and Thomas Pfohl — University of Basel, Basel, Switzerland

Components of the cytoskeleton are generally geometrically confined in cells, thus the range of physical dynamics exhibited by polymers in response to external confinement is connected to our understanding of biological systems. Using a microfluidic platform, we have studied the effects of varying geometrical confinements on the semi-flexible biopolymer actin. We have designed microfluidic devices, containing separate micro-confinements of differing geometries, which may exchange macromolecules and ions with a connected inlet channel via diffusion. Hence, we are able to observe the polymerization of actin filaments in vitro within diffusion-controlled micro-confinements, subject to various geometrical parameters. Furthermore, it is possible to create a macromolecular concentration gradient across the micro-

confinements, enabling the control of actin filament polarity during polymerization. Observations of single-filament and multiple-filament fluctuations are correlated, and the distribution of single filaments and filament networks are analyzed. Imposing a progressively narrower confinement has been shown to dampen polymer fluctuations and alter their distribution, while constraining filaments to increasing angles of external curvature is found to primarily affect the distribution of polymers within the confinement.

BP 11.8 Tue 9:30 P1

Active Microrheology: Mechanical Properties of In Vitro Assembled Keratin Networks — Tobias Paust[1], Katinka Mertens[1], Ines Martin[1], Tobias Neckernuss[1], Michael Beil[2], and •Othmar Marti[1] — [1]Institute of Experimental Physics — [2]Department of Internal Medicine I

Macro- and microrheology is extensively used to characterize complex networks of biopolymers. From this data one infers mechanical properties affecting migration or the response to external stresses. So far macro- and microrheology give similar but not identical responses.

The aim in these studies is to gather information about the dynamic mechanical properties of in vitro assembled keratin 8/18 networks realized by an optical tweezers setup.

In this work we explore the possibility of multi-point microrheology to determine locally the complex tensorial elastic response of heterogeneous networks. We use the measurements to find possible differences between macro- and microrheology. A careful analysis of the data provides additionally the frequency response of the complex elastic tensor. Furthermore, it is possible to determine phase dependencies between excitation and response. We show the data of measurements of in vitro assembled keratin 8/18 networks with varying Mg2+ concentrations.

BP 11.9 Tue 9:30 P1

Nonlinear elasticity of cross-linked networks — •Karin John[1], Denis Caillerie[2], Philippe Peyla[1], Annie Raoult[3], and Chaouqi Misbah[1] — [1]Université Grenoble 1/CNRS, LIPhy UMR 5588, F-38041 Grenoble, France — [2]L3S-R, B.P. 53, F-38041 Grenoble Cedex 9, France — [3]Laboratoire MAP5 UMR 8145, Université Paris Descartes/CNRS, F-75270 Paris Cedex 06, France

Cross-linked semiflexible polymer networks are omnipresent in living cells. Typical examples are actin networks in the cytoplasm of eukaryotic cells, which play an essential role in cell motility, and the spectrin network, a key element in maintaining the integrity of erythrocytes in the blood circulatory system. We introduce a simple mechanical network model at the length scale of the typical mesh size and derive a continuous constitutive law relating the stress to deformation. The continuous constitutive law is found to be generically nonlinear even if the microscopic law at the scale of the mesh size is linear. The nonlinear bulk mechanical properties are in good agreement with the experimental data for semiflexible polymer networks, i.e., the network stiffens and exhibits a negative normal stress in response to a volume-conserving shear deformation, whereby the normal stress is of the same order as the shear stress. Furthermore, it shows a strain localization behavior in response to an uniaxial compression.

The presented theory provides a basis for the continuum description of polymer networks such as actin or spectrin in complex geometries and it can be easily coupled to growth problems, as they occur, for example, in modeling actin-driven motility.

BP 11.10 Tue 9:30 P1

Equilibrium Dynamics of Helical Polymers — •Lorenz Huber, Philipp Lang, and Erwin Frey — Arnold Sommerfeld Center for Theoretical Physics and Center for NanoScience, Department of Physics, Ludwig-Maximilians-Universität München, Germany

Biopolymers like DNA, cytoskeletal filaments or artificially designed DNA-origami fibres are elastic nanoparticles that form helical configurations in their ground state. The handedness, radius and pitch of these helices are determined by their curvature κ and torsion τ. Their statistical mechanics is described by the helical wormlike chain model, where κ, τ are identified as the filaments' intrinsic bending and twisting rates, respectively.

Here we employ Brownian dynamics simulations to investigate the thermal end-to-end distance fluctuations. We find that $\langle \delta R^2(t) \rangle$ exhibits a rich scaling behavior with varying κ and τ. For $\kappa = 0$ the initial relaxation resembles the $t^{3/4}$-scaling law as predicted by semiflexible polymer theory. In contrast, helices with a low ascending pitch angle, i. e. $\kappa > \tau$, show power law exponents exceeding 3/4 due to the additional elastic modes of the spring-like polymer conformation. The crossover region with $\kappa < \tau$ reveals a sudden intermediate relaxation regime with a scaling exponent well below 3/4. With rising τ this domain only slowly converges towards the semiflexible limiting case.

Our findings demonstrate the intriguing influence of helical parameters on the dynamics of single polymer systems and can in principle help to determine structural details beyond the resolution of (static) experimental techniques.

BP 11.11 Tue 9:30 P1

Mechanical Properties of Keratin Bundles in Living Cells — •Jens-Friedrich Nolting and Sarah Köster — Institute for X-Ray Physics, University of Göttingen, Germany

Intermediate filaments are a major component of the eukaryotic cytoskeleton along with microtubules and microfilaments and play a key role in cell mechanics. Here, we present a study of keratin intermediate filament bundles in living cells. Intracellular forces in combination with cytoskeletal cross-talk lead to buckling of the keratin bundles. By investigating these buckling events *in situ* we conclude upon the mechanical properties of the keratin bundles and their environment. In brief, we measure the buckling wavelength and the bundle diameter of the events using live cell confocal microscopy. From these data we then deduce the elastic modulus of the surrounding matrix and the persistence length of the bundle. Furthermore, we evaluate the strength of the coupling between the individual filaments inside a keratin bundle by fitting a coupling factor to our data. Our findings suggest that the coupling between the filaments within a bundle is predominantly strong but it allows for some movement of filaments with respect to each other.

BP 11.12 Tue 9:30 P1

Subunit exchange in vimentin intermediate filaments — •Bernd Nöding and Sarah Köster — Institute for X-Ray Physics, University of Göttingen, Germany

Intermediate filaments, together with actin filaments and microtubuli and in combination with motorproteins and binding proteins make up the cytoskeleton of eukaryotic cells. While assembly mechanisms for different intermediate filaments have been modeled in the past, insights into the dynamic changes in the filament cross-section are still largely missing. Thus, we perform measurements of the exchange of fluorescently labeled subunits on fully assembled vimentin intermediate filaments. We find that an exchange of subunits occurs at a temperature dependent rate. Likely, polymorphism of the filament cross-section is an important factor in this process. With these findings, we aim to contribute to a more comprehensive description of the assembly and subunit exchange mechanism.

BP 11.13 Tue 9:30 P1

Studying the assembly of intermediate filaments in microfluidic channels using fluorescence cross correlation spectroscopy (FCCS) — •Viktor Schroeder[1], Bernd Nöding[1], Anja Niedermayr[2], Harald Herrmann[3] und Sarah Köster[1] — [1]Institute for X-Ray Physics, Georg-August-University Göttingen, Göttingen, Germany — [2]Department of Neurophysiology and Cellular Biophysics, Georg-August-University Göttingen, Göttingen, Germany — [3]Division of Molecular Genetics, German Cancer Research Center (DKFZ), Heidelberg, Germany

The cytoskeleton of eukaryotes consists of three different filamentous systems: microtubules, actin filaments and intermediate filaments (IFs). While both tubulin and actin are highly conserved, IF proteins occur in many different variations, depending on cell type and organism. All cytoskeletal filaments consist of distinct subunits and assemble in a characteristic way. For vimentin IFs, which are found in cells of mysenchymal origin, a principal assembly model exists. However, measurements of the assembly process with high time resolution, which would yield insight especially into the early assembly steps, are still largely missing. To approach this problem, we use fluorescence cross correlation spectroscopy (FCCS) in combination with microfluidic continuous flow mixers to access time scales in the millisecond range and directly follow binding events.

BP 11.14 Tue 9:30 P1

Magnetic interactions in the magnetosome chain of magnetotactic bacteria — •Bahareh Kiani and Stefan Klumpp — Max Planck Institute of Colloids and Interfaces, Potsdam, Germany

Magnetotactic bacteria are aquatic microorganisms that swim and orient in the direction of magnetic field due to the presence of the magne-

tosome chain, a chain of vesicle-enclosed magnetic nanoparticles that are aligned on a cytoskeletal filament [1]. Here we investigate magnetic interactions between the nanoparticles to study the contribution of magnetism to the persistence length of the chain. The calculation of the energy of a curved magnetosome chain shows that magnetic interactions contribute only little to the stiffness of the chain, which should be mostly attributed to the filament. Furthermore, magnetic interactions favor closed-ring chains, and attachment to the filament can stabilize the chain against ring closure.

[1] Dirk Schüler, *Magnetoreception and Magnetosomes in Bacteria* (Springer, 2006).

BP 11.15 Tue 9:30 P1

Elastic response of pre-stressed 3D filamentous networks with compliant crosslinks — •Knut Heidemann[1], Meenakshi Prabhune[2], Florian Rehfeldt[2], Christoph Schmidt[2], and Max Wardetzky[1] — [1]Institut für Numerische und Angewandte Mathematik, Georg-August-Universität Göttingen — [2]Drittes Physikalisches Institut - Biophysik, Georg-August-Universität Göttingen

The cytoskeleton of cells is a composite network of filaments ranging from stiff rod-like microtubules to semiflexible actin filaments that together play a crucial role for cell structure and mechanics. The collective dynamics of these cytoskeletal filaments with widely different mechanical properties yet remain to be understood completely.

To model a strongly heterogeneous composite, we set up 3D simulations of filamentous networks with compliant crosslinks, and extract elastic moduli via quasistatic deformations.

Furthermore, We introduce an affine theory that captures the simulation results correctly. In particular, we derive asymptotic exponents for the scaling of the differential modulus with stress in the limit of infinite crosslink densities. Numerical results for finite numbers of crosslinks are presented as well.

In addition, we analyze the effects of pre-stress, which is easily tunable in our simulations. It turns out that the initial normal stress can be related to the linear shear elastic modulus, and might therefore be of importance for experimental studies as well.