BP 19: Focus session: Physics of cilia: Dynamics of synchronized oscillators

Time: Wednesday 15:00–17:00 Location: H11

Invited Talk BP 19.1 Wed 15:00 H11

Self-organized wave-like beating of actin bundles — Marie Pochitaloff[1], Mathieu Richard[1], Takagi Yasuharu[2], Wenxiang Cao[3], Enrique De La cruz[3], Jim Sellers[2], Jean-François Joanny[1], Frank Jülicher[4], Laurent Blanchoin[5], and •Pascal Martin[1] — [1]Institut Curie, Paris, France — [2]NHLBI-NIH, Bethesda, USA — [3]Yale University, New Haven, USA — [4]MPIPKS, Dresden, Germany — [5]CEA, Grenoble

The emergent active behaviors of systems comprising large numbers of molecular motors and cytoskeletal filaments remain poorly understood, even though individual molecules have been extensively characterized. Here, we show in vitro with a minimal acto-myosin system that flagellar-like beating emerges naturally and robustly in polar bundles of filaments. Using surface micro-patterns of a nucleation-promoting factor, we controlled the geometry of actin polymerization to produce thin networks of parallel actin filaments. With either myosin Va or heavy-mero myosin II motors added in bulk, growing actin filaments self-organized into bundles that displayed periodic wave-like beating resembling those observed in eukaryotic cilia and flagella. We studied how varying the motor type or changing the size of the actin bundles influenced the properties of the actin-bending waves. In addition, using myosin-Va-GFP to visualize the motors within the actin bundle, we identified a novel feedback mechanism between motor activity and filament bending. Overall, structural control over the self-assembly process provides key information to clarify the physical principles underlying flagellar-like beating.

BP 19.2 Wed 15:30 H11

Toward synthetic cilia: bending oscillations of a microtubule-dynein system — •Isabella Guido[1], Ramin Golestanian[1], Andrej Vilfan[1], Eberhard Bodenschatz[1], and Kazuhiro Oiwa[2] — [1]Max-Planck Institute for Dynamics and Self-organization, Göttingen, Germany — [2]National Institute of Information and Communications Technology , Kobe, Japan

Cilia and flagella produce rapid and regular bending waves responsible for the propulsion of organisms in fluids or for the promotion of fluid transport. It is known that the main contribution to their beating is due to motor proteins, dynein, which drives sliding of the microtubule doublets. However, the fundamental mechanism of the dynein-microtubule interaction is still a puzzle. Here we investigate their mechanical interaction and emergent behavior by analyzing a minimal synthetic system that we experimentally assemble with two microtubules and few dynein motors. We observe that the microtubule pair undergoes cyclical association/dissociation interaction through rhythmic bending, followed by a complete detachment of the microtubules and subsequent re-attachment. By considering the shearing force produced by the motors when they move along the adjacent microtubule and the finite elasticity of the system, we describe this beating cycle in terms of the curvature and dynein-microtubule binding force.

This work is supported by the BMBF and MPG through the MaxSynBio initiative.

BP 19.3 Wed 15:45 H11

Reconstitution of bio-mechanical oscillations in a minimal system — •Monique Honsa, Veikko F. Geyer, and Stefan Diez — B CUBE, TU Dresden, Germany

Bio-mechanical oscillations drive important biological processes through the dynamic interplay of molecular motors and filaments. To better understand the fundamental mechanism of the generation of oscillations in a minimal system, we realized a bottom-up approach of a bio-mechanical oscillator by using only three components – molecular motors, filaments and cross-linkers. In an *in vitro* kinesin-1 gliding motility assay, we cross-linked the leading tips of microtubules to the glass surface and observed the rhythmical buckling of the trailing parts of the microtubules with frequencies of 40 mHz and amplitudes of 2.5 μm. Remarkably, during buckling, parts of the microtubules moved up to three times faster than the gliding velocity of the microtubules. Our observations provide insight into the fundamental mechanisms involved in the generation of oscillations in motor-filament systems and are expected to lead to a better understanding of dynamic biological processes such as the flagellar beat.

BP 19.4 Wed 16:00 H11

SpermQ - a simple analysis software to comprehensively study flagellar beating and sperm steering — •Jan N Hansen[1], Sebastian Rassmann[1], Jan F Jikeli[1], and Dagmar Wachten[1,2] — [1]Institute of Innate Immunity, Biophysical Imaging, University Hospital Bonn, University of Bonn, 53127 Bonn, Germany — [2]Center of Advanced European Studies and Research (caesar), Molecular Physiology, 53175 Bonn, Germany

Motile cilia, also called flagella, are found in many species; some cilia propel cells like sperm, while cilia on epithelia create complex fluid patterns e.g. in the brain or lung. For sperm, the picture has emerged that the flagellum is not only a motor, but also a sensor, computing the beat pattern based on environmental cues and thereby, navigating the sperm through the female genital tract. It has been proposed that distinct flagellar signaling domains control the flagellar beat. However, a detailed analysis has been mainly hampered by the fact that current comprehensive analysis approaches rely on complex microscopy and analysis systems. Thus, knowledge on signaling regulating the flagellar beat is based on custom quantification approaches that are limited to only a few parameters, do not resolve the entire flagellum, rely on qualitative descriptions, and are little comparable among each other. Here, we present SpermQ, a ready-to-use and comprehensive analysis software to quantify sperm motility in common time-lapse images acquired by dark-field microscopy. We envision SpermQ becoming a standard tool in motile cilia and flagella research that allows to readily link individual signaling components and distinct flagellar beat patterns.

BP 19.5 Wed 16:15 H11

Meet the beat: an inter-species study of the 3-dimensional flagellar beat — •An Gong[1], Sebastian Rode[2], Rene Pascal[1], Benjamin Friedrich[3], Jens Elgeti[2], Stephan Irsen[1], Luz Perez[4], Gerhard Gompper[2], Benjamin Kaupp[1], and Luis Alvarez[1] — [1]Center of Advanced European Studies and Research (caesar), Bonn, Germany — [2]Institute of Complex Systems, Jülich, Germany — [3]Center for Advancing Electronics, Dresden, Germany — [4]Instituto de Ciencia y Tecnología Animal, València, Spain

Sperm capture sensory cues that are processed and translated into a time pattern of three-dimensional (3D) flagellar beat for propulsion and steering to find the egg. However, sperm of different species are confronted with quite different fertilization habitats and, accordingly, differ greatly in behaviors. The 3D flagellar beat pattern underlying behaviors and the molecular mechanism involved are not yet understood.

We used holographic microscopy to study the 3D movement of sperm flagella and the resulting swimming behaviors across different species including two external (sea urchin and eel) and two internal (human and mouse) fertilizers. The difference and commonalities among sperm from diverse species are described with a focus on sea urchin and human sperm. Furthermore, we describe novel features of the beat that underlie the sperm behaviors and we propose a link between these 3D beat features and internal flagellar structures.

BP 19.6 Wed 16:30 H11

Actuation of artificial cilia with surface acoustic waves — •Gerhard Lindner — Institut für Sensor- und Aktortechnik, Hochschule Coburg, 96450 Coburg, Germany

Surface acoustic waves such as Rayleigh or Lamb waves generate displacements at the surface with larger amplitudes than in the bulk volume. By them a periodic movement of cilia, whose tracing point is fastened at the surface, can be actuated. In case of an asymmetric bending stiffness of such cilia it is possible to excite a directional streaming in a fluid, which enables a pumping of this fluid. In particular, this allows an advantageous modification of the streaming profile in the boundary layer neighboring a solid wall. Corresponding estimations will be presented in this contribution. The concept is matter of the European patent EP 2545369 "Apparatus producing and/or detecting a flow in a medium" granted on May 30, 2018.

BP 19.7 Wed 16:45 H11

Light-Switchable Adhesive Functionalities of Eukaryotic Flagella — Christian Titus Kreis, Christine Linne, Marine Le

Blay, Anni Röse, and •Oliver Bäumchen — Max Planck Institute for Dynamics and Self-Organization, D-37077 Göttingen, Germany

In contrast to marine phytoplankton, many photoactive microbes live in complex environments, such as liquid-infused soil and moist rocks, where they encounter and colonize a plethora of surfaces. We discovered that the flagella-mediated adhesion of the unicellular, eukaryotic microalga *Chlamydomonas* to surfaces can be reversibly switched on and off by light [1]. Our *in vivo* micropipette force spectroscopy (MFS) experiments [2] suggest that light-switchable adhesiveness is a natural functionality of flagella to actively regulate the transition between freely swimming (planktonic) and surface-associated state, which yields an adhesive adaptation of microbes to optimize their photosynthetic efficiency in variable and inhomogeneous light conditions. The kinetics of this transition can be readily probed by MFS experiments, where the cell actively pulls itself towards the substrate (auto-adhesion) until the cell achieves its gliding configuration on the surface. We show that the associated forces are exerted by molecular motors, which are connected to individual flagella-surface contacts. In conclusion, eukaryotic flagella are multifunctional cellular appendages that are not only essential for microbial propulsion but also for cellular adhesion to surfaces.

[1] C.T. Kreis et al., *Nature Physics* 14, 45-49 (2018).
[2] M. Backholm & O. Bäumchen, *Nature Protocols* (in press).