DY 17: Physics of Physarum polycephalum and Other Slime Molds - Joint Focus Session (BP/DY) organized by Hans-Günther Döbereiner

Time: Tuesday 9:30–13:00 Location: SCH A251

Invited Talk DY 17.1 Tue 9:30 SCH A251

Laminar mixing in tubular networks of plasmodial slime moulds — •Marcus Hauser — Otto-von-Guericke-Universität Magdeburg, Institut für Biometrie und Medizinische Informatik, Magdeburg, Germany

The plasmodium of the unicellular slime mould *Physarum polycephalum* forms an extended, at times giant, vascular network which is used for transportation of protoplasm through the cell. The transport is driven by pressure gradients generated by peristaltic pumping, leading to a flow that reverses its direction periodically. Although the flow in the veins of *P. polycephalum* is always parabolic, protoplasm and particles suspended in it are effectively and rapidly distributed within the cell. To elucidate how an effective mixing is achieved in such a microfluidic system with Womersley flow (at low Womersley and Reynolds numbers), we performed micro-PIV experiments and advect virtual tracers in the determined time-dependent flow fields. Flow splitting and flow reversals at branchings of veins, as well as small fluctuations in the flow patterns at the branchings of veins play key roles in providing for an efficient mixing of protoplasm in the cell.

DY 17.2 Tue 10:00 SCH A251

Calcium dynamics in *Physarum polycephalum* — •Mirna Kramar and Karen Alim — Max Planck Institute for Dynamics and Self-Organization, Göttingen, Germany

Calcium is a known regulator of myosin across all living organisms, as well as a key player in cell signalling. We study the effects of calcium on morphogenesis, locomotion and healing in the plasmodium of *Physarum polycephalum. Physarum* is a giant multinucleate and unicellular organism. The organism uses peristaltic contractions of the actomyosin layer to create shuttle streaming of the cytoplasm throughout its network of tubes. Upon a change of environmental conditions, the contractions change and cause a reorganization of the network. The mechanism that propagates information within the body and results in the network reorganization is not yet clear. We hypothesise that calcium plays the key role in this process by directly influencing the myosin and thus causing a local change in the contractions. Using an approach with two fluorescent dyes, we label free calcium ions and show the response of calcium upon the application of various stimuli to the plasmodium.

DY 17.3 Tue 10:15 SCH A251

Light stimuli trigger local and global cellular response in *Physarum polycephalum* — •Felix Bäuerle and Karen Alim — Max Planck Institute for Dynamics and Self-Organization, Göttingen, Germany

The slime mold *Physarum polycephalum* excels in adapting its network-like morphology to its environment. As a giant, single cell it is able to collect localised cues and form a complex organism-wide response. For example, *Physarum* can find the shortest path in a maze and connect sparse food sources to choose a balanced diet. How are localised cues collected, integrated and mediated over the whole organism to perform theses complex tasks? To tackle these questions we study *Physarum*'s pruning reaction to light stimuli. *Physarum*'s body consists of protoplasmic tubes which contract rhythmically. These contractions show distinct temporal patterns until pruning is completed. We found that *Physarum* shows a whole-cell response shortly after light application and then gradually transforms the illuminated region into an autonomous domain. Identifying the interplay between such global and local reactions may advance our understanding of more general processes like wound healing or cell signalling.

DY 17.4 Tue 10:30 SCH A251

Scaling of foraging patterns under starvation in *Physarum polycephalum* — •Jonghyun Lee, Christina Oettmeier, and Hans-Günther Döbereiner — Institut für Biophysik, Universität Bremen

Physarum polycephalum is garnering attention as a model organism for primitive intelligence and decision-making. We utilize microplasmodia, quasi-spherical fragments on the micrometer range, to investigate the reconstitution of the macroplasmodium from smaller components.

Generally, *Physarum* grows as an extended network, of which the transition from micro- to macroplasmodia occurs via percolation [1]. However, under starvation conditions, this transition does not occur. Instead, several bodies on the millimeter scale form and migrate radially away from the site of inoculation. We term these motile mesoplasmodia *satellites.* Satellite growth mode has defined phases of motility and rest, and their behaviour is spatio-temporally correlated. Satellites also have a stable and defined morphology, as well as a constant direction of movement.

Here, we present a description of this growth mode with simplified geometrical shapes. We describe scaling relationships of the number of satellites produced and their size based on initial conditions. The model predicts the size to increase and the number to decrease as the initial biomass increases, which fits well with the data. We discuss implications of assumptions and limitations of our scaling model.

[1] Fessel, A. et al. (2012), *Physical Review Letters* 109, 078103.

DY 17.5 Tue 10:45 SCH A251

Hydrodynamic Mechanism of Information Processing in *Physarum polycephalum* — •Christina Oettmeier, Jonghyun Lee, and Hans-Günther Döbereiner — Institut für Biophysik, Universität Bremen

P. polycephalum exhibits rich spatiotemporal oscillatory behaviour. The organism's size spans orders of magnitude, from meter-sized networks to micrometer-sized amoebae. All morphotypes show actomyosin-based contraction-relaxation cycles resulting in protoplasmic streaming. When a food source is encountered, oscillations at the stimulated site increase in frequency. If repellents are encountered, the local oscillation frequency decreases [1]. This either leads to movement towards the attractant or away from the repellent. We study hydrodynamic information processing in amoeboid locomotion. Autonomous foraging units (mesoplasmodia) maintain their shape over hours while moving in straight trajectories at constant mean speed. Oscillations in the back of the mesoplasmodium cause endoplasm flows through the internal vein system and expand the frontal membrane. Frequencies at the back are higher than those at the front due to filtering. We use the electronic-hydraulic analogy to investigate this case of information processing. A vein segment can be described as a flexible tube, possessing a fluidic resistance (R) and fluidic capacitance (C). The electronic equivalent is a passive RC low pass filter. We use SPICE to simulate vein behaviour. Light- and EM data of mesoplasmodia and other morphotypes provide geometrical and elastic parameters.

[1] Durham, A.C.H. & Ridgway, E.B. (1976), *J.Cell Biol.* 69, 218-223

15 min break

DY 17.6 Tue 11:15 SCH A251

Control of Pattern Formation in *Dictyostelium discoideum* — •Torsten Eckstein, Albert Bae, Vladimir Zykov, Eberhard Bodenschatz, and Azam Gholami — Max Planck Institute for Dynamics and Self-Organization, Göttingen, Germany

We performed experiments to study pattern formation in colonies of *Dictyostelium discoideum* cells under the influence of a regular array of pillars in a petri dish.

We observed a new phenomenon: In the presence of caffeine, synchronized circular waves center on the pillars and dominate the wave dynamics. In a periodic arrangement of pillars, this results in regular macroscopic streaming patterns reminiscent of Voronoi domains centered around the pillars. The shape of these Voronoi domains is based on the underlying shape of the array of pillars. Thus, the macroscopic pattern can be tuned by changing the geometry of the array. We have shown that this phenomenon is found for different geometries, like a rectangular grid of pillars, a hexagonal grid of pillars and long walls as obstacles. It seems the defining characteristic in the system is the presence of a wall. Indeed, the phenomenon persists for pillars of a small height and shallow holes. Additionally, we varied the initial starvation times of the cells, finding that cells stream to the pillars for starvation times from 40 minutes to 7 hours. However, for starvation times of at least 5 hours the macroscopic pattern was lost.

DY 17.7 Tue 11:30 SCH A251

***Physarum polycephalum* single cells proceed through variable trajectories of gene expression to commitment and differentiation** — •Wolfgang Marwan — Magdeburg Centre for Systems Biology, Otto-von-Guericke University, Magdeburg

Physarum polycephalum multinucleate giant plasmodial cells with their naturally synchronous population of nuclei provide ample homogeneous biological material for the analysis of signaling and gene expression dynamics at the single cell level. The developmental program of sporulation was triggered by a brief pulse of far-red light. By taking samples at different time points after the stimulus pulse, we followed how the gene expression pattern changes during commitment and differentiation. Time-dependent patterns of differential gene regulation showed that developmental trajectories were highly variable between individual cells. Differentiation control mutants that are locked in the proliferative state responded to the stimulus pulse by taking altered trajectories of gene expression that did not lead to sporulation. The results are discussed in the context of a Waddington-type quasipotential landscape of cell differentiation and the impact of mutations on its topology. We further discuss how *Physarum polycephalum* can contribute to a data-driven theoretically sound dynamic systems approach to the regulatory control of eukaryotic cell differentiation at genome-wide scale.

DY 17.8 Tue 11:55 SCH A251

Evolutionary experiments with slime molds — •Martin Grube — Institute of Plant Science, University Graz, 8010 Graz, Austria

Acclimatisation describes adaptive physiological or behavioural changes of an organism, whereas adaptation is a process that involves heredity of selected traits. Slime molds seem to use information about past experiences for optimal decision-making, which is a simple form of learning. Yet it is still unclear to what extent this type of learning is mediated by acclimatization, habituation, or by hereditary adaptation. If slime molds can adapt by hereditary mechanisms to a wider range of growth conditions, and modify their growth features and foraging patterns accordingly, the diverged strains should then consistently differ by these properties, even when grown under the same conditions. We use serial transfers of plasmodia to select the best performing plasmodium after each transfer. By using microplasmodia initially we generate a genetic bottleneck to increase genetic drift. In our work we encountered several challenges, including the size variation of microplasmodia, which may cause a bias in the selection procedure, and which need to be addressed.

DY 17.9 Tue 12:20 SCH A251

Mechanochemical pattern formation in simple models of active viscoelastic fluids and solids with application to *Physarum polycephalum* — Sergio Alonso[1], Markus Radszuweit[2], Harald Engel[3], and •Markus Bär[4] — [1]Department of Physics, UPC Barcelona, Spain — [2]Weierstrass Institute Berlin, Germany — [3]Theoretische Physik, Technische Universitaet Berlin, Germany — [4]Physikalisch-Technische Bundesanstalt, Abbestrasse 2-12, 10587 Berlin, Germany

A simple description for active stress generation is coupled to different model of passive viscoelasticity. Specifically, two models for viscoelastic fluids (Maxwell and Jeffrey model) and two models for viscoelastic solids (Kelvin-Voigt and Standard model) are investigated. Our focus is on the onset of mechano-chemical waves and patterns. We carry out linear stability analysis and numerical simulations in one spatial dimension. The primary instability is stationary for all active fluids considered, whereas all active solids exhibit an oscillatory instability. All instabilities found are of long-wavelength nature. The special case of a poroelastic two-phase model, where the active solid represents the cytoskeleton and is described by a Kelvin-Voigt model is coupled to a viscous fluid (cytosol) in which the free calcium concentrations obeys a potentially oscillatory reaction-diffusion dynamics. M. Radszuweit, H. Engel, M. Bär, PLoS One 2014; S. Alonso et al. Physica D 2016.

DY 17.10 Tue 12:45 SCH A251

Poroelastic two-phase model for droplets of *Physarum polycephalum* with free boundaries — •Dirk Alexander Kulawiak[1], Jakob Löber[1], Markus Bär[2], and Harald Engel[1] — [1]Institut für Theoretische Physik, TU Berlin, Hardenbergstrasse 36, 10623 Berlin, Germany — [2]Physikalisch-Technische Bundesanstalt, Abbestrasse 2-12, 10587 Berlin, Germany

The model describes the cytoskeleton as an active viscoelastic solid phase coupled to a passive viscous fluid representing the cytosol. The active tension in the solid phase depends on the concentration of a regulating agent that is advected by the fluid phase. In [1] it was shown that under rigid boundary conditions that impose a fixed shape, this model reproduces a large variety of mechano-chemical patterns; these include traveling and standing waves, turbulent patterns, rotating spirals and antiphase oscillations in line with experimental observations of contraction patterns in protoplasmic droplets of *Physarum polycephalum.* Here we present a free-boundary approach to the model of the moving droplet. We find deformations of the droplet boundary as well as oscillatory and chaotic changes in the droplets position.