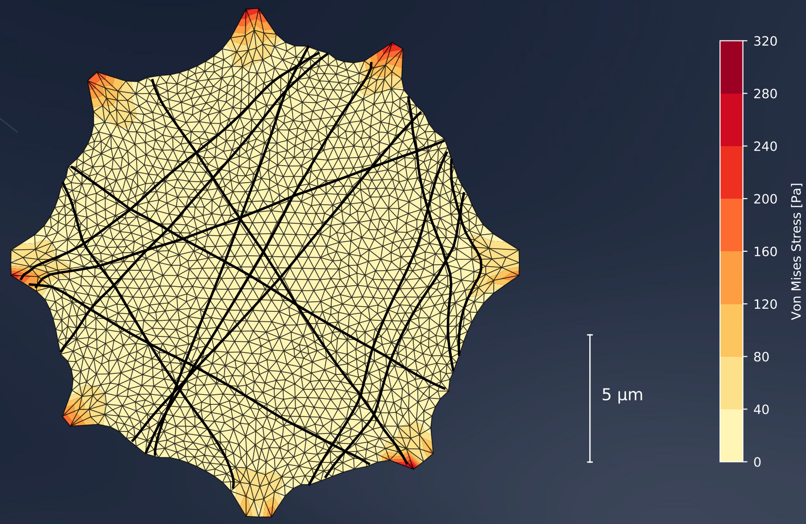
STRUCTURES | NEWS

STRUCTURES CLUSTER OF EXCELLENCE

UNIVERSITÄT HEIDELBERG ZUKUNFT SEIT 1386

Two-dimensional, linear elastic model of a circular, homogeneous cell with contractile actin stress fibers that is pinned at eight points of its outer membrane. The grid for the finite element method is visualized with thin grey lines, and colors indicate the von Mises stress. Stress fibers are visualized as black lines and distributed by a genetic algorithm to minimize both the overall stress in the cell and the amount of material used to build the fibers.



Feb 2022

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June 21, 22: Mid-Term Review External Advisory Board

More Information can be found on the STRUCTURES website.

New Exploratory Projects

We are delighted to announce three new Exploratory Projects (EPs) that will open up new research directions in our cluster:

EP 6.1: Reconstructions of potentials with neural differential equations: applications to cosmic inflation and dark energy *(B.M. Schäfer)*

EP 6.2: Learning and predicting Covid-19 disease dynamics using dynamical systems reconstruction and Bayesian inference. *(D. Durstewitz, S.T. Radev, U. Köthe, C. Dullemond)*

EP 6.3: Universality of Structure Formation from Gaussian Random Fields *(S. Konrad, M. Bartelmann, M. Salmhofer)*

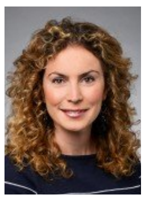
Lauriane Chomaz Receives ERC Starting Grant


Lauriane Chomaz

We congratulate Lauriane Chomaz, professor at PI, for receiving an ERC Starting Grant for her research work on two-dimensional dipolar quantum gases. The prestiguous award, which comes with a high amount of funding, is awarded by the European Research Council (ERC). For this newsletter, we interviewed Lauriane for our *"STRUCTURES asks"* format on page 2.

STRUCTURES Members News

In the beginning of this term, STRUCTURES has been happy to welcome three new members. Lavinia Heisenberg, formerly ETH Zürich, joined ITP as a professor, further strengthening cosmological research. Wolfram Pernice, formerly Münster University, joined KIP as a professor, where he leads the Neuromorphic Quantum Photonics Group. Falko Ziebert is a permanent staff member of the ITP. His work focuses on nonlinear and non-equilibrium physics in soft matter and biological systems (see also the CP Report on page 3). We warmly welcome the three and look forward to inspiring collaborations!


Lavinia Heisenberg


Wolfram Pernice


Falko Ziebert

We are delighted that Gabriele Benedetti, Stefan Flörchinger and Björn Ommer will remain external members, and wish them all the best for their new positions. Gabriele Benedetti accepted an assistant professorship at VU Amsterdam. Stefan Flörchinger succeeds Andreas Wipf as professor for quantum field theory at FSU Jena. Björn Ommer started a professorship at LMU Munich.

MEMBER INTERVIEWS

STRUCTURES asks: Lauriane Chomaz

In our newsletter, we regularly present interviews with STRUCTURES faculty members to give you the opportunity to get to know them a little better. For this edition, we interviewed Lauriane Chomaz. Since February 2021, she leads the experimental physics group "Quantum Fluids" at Physikalisches Institut (PI). She received the third STRUCTURES professorship and is involved in two EPs: 5.2: "Structure formation in driven Bose-Fermi mixtures" and EP 4.8: "A new experimental platform for exploring self-organization in dipolar quantum gases."

Lauriane Chomaz is STRUCTURES Professor at Physikalisches Institut (PI), where she leads the experimental "Quantum Fluids" group. (Image: © Tobias Schwerdt and Lauriane Chomaz, adapted by merging two partial images).

What are you working on? I work on ultracold quantum gases, and, in my new experiment, more particularly on gases made of atoms with strongly magnetic properties. The atoms therefore interact as magnets. What I am interested in are the quantum states that realise the gas of magnets at ultralow temperature, when playing with their interactions and confinement.

Why is it fascinating for you? I like that we are studying things that are so simple and basic, in a sense — I mean it is just a bunch of atoms – and yet the system is so rich that we can realise many different conditions and in particular implement textbook models from which we can try to help understand effects in more complex systems.

What research question would you really like to answer? For now, what I would like to understand better is how complex quantum orders and structures can form in (magnetic) atomic gases.

Why did you choose to study physics? I was born into it, actually. I tried a few somewhat different things, but eventually I came back. I like how physics tries to describe things in a universal and apparently simple way, and how it connects simple things from our daily life to deeper effects that underlie our universe.

Any advice for young researchers in choosing their career path? If I take inspiration from my case for this advice, it would be: do what you like, have good mentors, and most importantly, stay open to what you think you will not or cannot do.

What do you like best in your job? I like that it is always somehow challenging, and always somehow in a very nice way. One needs to bring so many different aspects of knowledge (theoretical, technical, etc.) together to be able to tackle the challenges. Most of all, we take the challenges as a team and it needs a good team to be able to solve them. I also like to see how the different personalities of the different people come together into developing the solutions that we implement at the end and how all this is connected.

What is your connection to STRUCTURES? STRUCTURES constitutes the full background for the development of my current research. I developed the concept of my apparatus in strong connection with STRUCTURES' project, in particular with the Heidelberg Quantum Architecture at the heart of CP4. It is difficult for a freshly joining member to grasp the full scope of such a wide collaboration as STRUCTURES, therefore I enjoy very much the Jour Fixe, and especially the pretalk, to get an overview of all that is around. I hope to gain more inspiration from it for the future.

What was your greatest scientific success up to now? It is difficult for me to rank my different works. Objectively, I should certainly answer that the observation of supersolid behaviour in dipolar gases is my greatest scientific success. However, I am very much attached to preceding works like the observation of roton population in dipolar gases, or the observation of spontaneous vortices from Kibble-Zurek mechanism at the transverse condensation transition, because the path towards understanding the data was a long adventure for me and my team at the time.

Do you have a favourite particle or force? I like quasi-particles. They are more flexible than bare particles and change properties depending on circumstances. I like the electrostatic force, just because it is behind so many forces we are confronted with in our daily life, without us generally noticing it. As a rock-climbing enthusiast,, my favourite encounter with it is friction.

Imagine you get 48 extra hours as a present – what would you do with it? I think I get 48 hours extra approximately every two days already! ;)

CP REPORT

CP3: Modeling Cell Mechanics with the Finite Element Method

Invited article by F. Ziebert, L. Riedel, R. Chojowski, P. Bastian, U. Schwarz

Biological cells are masters of structure formation. Their proteins can bind to each other to form an enormous diversity of larger-scale structures. This higher order structure depends strongly on cell type, environmental conditions, and follows strictly controlled mechanisms. Mathematical models for biological structure formation usually come in two complementary flavors: either continuous models like field theories or discrete models like interacting particles. In CP3 we combine these different worlds for biological test cases like the emergence of "stress fibers" in adherent animal cells.

A biological cell in solution has little structure. In the moment it attaches to a surface, however, it typically develops a system of internal actin fibers, in order to adapt to the mechanics of the environment and to protect itself from the forces now applied to it (cf. Fig. 1a). Interestingly, stress fibers are not only passive elements with a high rigidity, but they are in addition actively contracted by molecular motors, very similar to the way muscles work and demonstrating the active nature of cells. Stress fibers become more prominent when the cell is mechanically stressed; see the experiments in Fig.1b [1]. They should be viewed as discrete active elements formed on demand and embedded into the continuous actin mesh giving the cell its background elasticity. We developed two complementary approaches to describe the coupling between continuous and discrete structures (the cell's elastic background vs. the fibers) including features of their self-organization dynamics and contractile activity.

The first approach is inspired from models developed for passive, fiber-reinforced systems such as reinforced concrete. It is based on the finite element method software package DUNE and implements the fibers implicitly [2]. That means, instead of discretizing fibers explicitly, which would demand an enormously refined grid and in the dynamic case even dynamic gridding, the fiber stress contribution from Euler beam theory is added to the respective grid cells of the bulk. Letting an initially isotropic and fiber-free cell contract under the action of motors, stress focusing at the attachment points occurs (Fig. 1c), which is used as the source of the fiber formation process. Using either a heuristic fiber growth process or a genetic algorithm that tries to minimize total stress yields fiber structures as exemplified for the latter algorithm in Fig. 1c [3].

A second modeling strategy builds more on continuum physics and uses the phase field approach that allows to efficiently describe moving boundaries. We developed a model including reversible elasticity [4] and are currently studying systems as shown in Fig. 1d. Here, the stress focusing at the attachment points in the scaffold triggers a phase transition to a nematic liquid crystalline order describing the fiber orientations.

Literature:

[1] Scheiwe, Andrea C.; Frank, Stephanie C.; Autenrieth, Tatjana J.; Bastmeyer, Martin; et al.; Biomaterials 44, 186 (2015).

[2] Hansbo, Peter; Larson, Mats G.; Larsson, Karl; in: S.P.A. Bordas et al. (eds.), Lecture Notes in Computational Sci ence and Engineering 121 (2017).

[3] Riedel, Lukas; Kempf, Dominic; et al.; in preparation (2022).

[4] Chojowski, Robert; Schwarz, Ulrich S.; Ziebert, Falko; Eur. Phys. J. E 43 (10), 1 (2020).

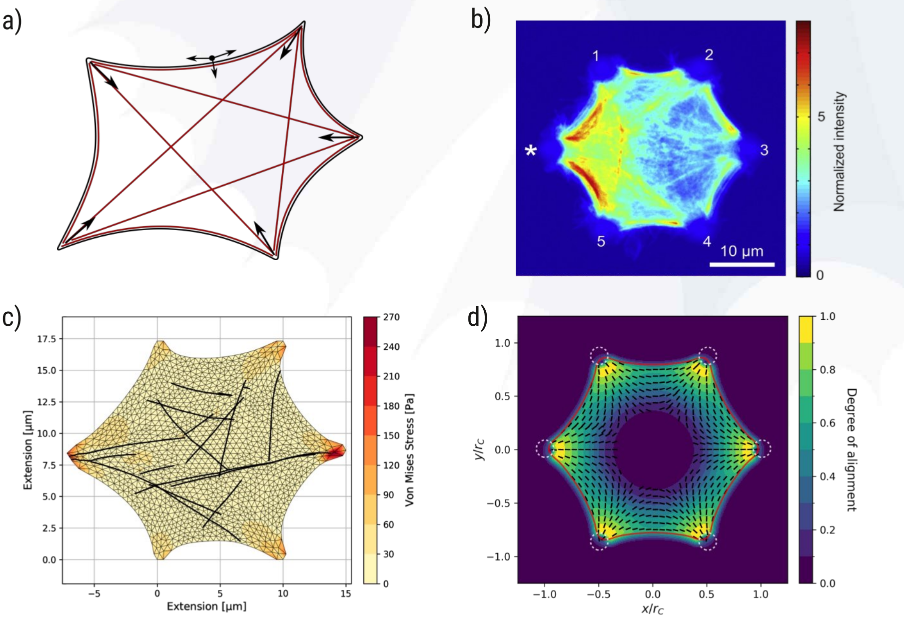


Fig. 1: *a)* Sketch of a spreading cell with stress fibers (red) and the associated contractile forces as arrows. *b)* Experimental data from [2] where scaffolded cells were continuously and reversibly stretched (at point *) and the actin fluorescent intensity was measured, showing the formation of stress fibers reinforcing the mechanically stressed regions (red). *c)* Finite element result for a scaffolded elastic cell with implicit fibers (black) that are initiated where the stress is highest (red) and dynamically grow and disappear to minimize the overall stress. *d)* Continuum phase field model for a scaffolded elastic cell where the stress initiates liquid crystalline order describing the fibers' mean orientation.

ABOUT CP3: FROM MOLECULES TO CELLS & TISSUE: COUPLING CONTINUOUS & DISCRETE STRUCTURES

The fundamental principles underlying the function of cellular and tissue systems are essential for both life sciences and new fields at the interface of medicine and materials science. Recent advances in life sciences have revealed that spatial structure is much more important than formerly appreciated e.g. for the compartmentalization of biological function, or in cell and tissue mechanics. Spatial structures often form as discrete or lower-dimensional components in a continuous background. In CP3, combining expertise from life sciences, biophysics, mathematics and computation, we advance continuum models and their finite element discretizations for different scenarios such as fiber systems that dynamically grow or reorganize in the cell, and for groups of specialized cells emerging in the context of a growing tissue.

STRUCTURES COMMUNITY

News from the YRC

The Young Researchers Convent (YRC) has elected Elena Kozlikin and Christophe Pixius as their new speakers in the General Assembly on January 27. We thank the previous speaker duo Christophe Pixius and Valentina Disarlo for their great commitment!

Elena Kozlikin
Postdoc & Principal Investigator, ITP

Christophe Pixius
PhD Student, AG Bartelmann, ITP

Upcoming Activities:

The YRC is happy about the growing number of members and planned activities:

- **YRC Stammtisch:** Beginning in March, the YRC Stammtisch will take place once a month. Meet, talk, have a drink or play games. We are looking forward to meet you! To join, contact Valentina Disarlo (vdisarlo[at]mathi.uni-heidelberg.de).
- **6th Schöntal Discussion Workshop** Aug. 16–19 for YRCs from physics & mathematics. Stay tuned for the registration call! Contact: Christoph Pixius (c.pixius[at]thphys.uni-heidelberg.de)
- **SAVE THE DATE: 1st STRUCTURES YRC Conference** Oct. 4–10 for all STRUCTURES members. Present your work, attend interesting keynotes, connect and start collaborations. Interested in joining the organization team? Contact Elena Kozlikin (e.kozlikin[at]thphys.uni-heidelberg.de)
- **Workshop on Holomorphic Curves and Dynamics**: TBA. Contact: Johanna Bimmermann (jbimmermann[at]mathi.uni-heidelberg.de)

Stay tuned for funding calls, the upcoming YRC Slack and a remodeled website!

STRUCTURES COMMUNITY

We Are STRUCTURES

In each newsletter, we introduce members of the Young Researchers Convent (YRC) to you. For this edition, we interviewed the newly elected YRC spokesperson Elena Kozlikin, postdoc at ITP, and Wilhelm Kroschinsky, exchange PhD student in Heidelberg.

Interview with Elena Kozlikin:

What are you working on? I am working on a novel theory to describe cosmic large-scale structure formation, called Kinetic Field Theory (KFT). I also apply KFT to other systems that are quite unlike the cosmological setting, such as ultracold plasmas.

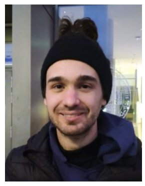
What are you an expert for? I am an expert for Kinetic Field Theory and cosmic structure formation.

What is your connection to STRUCTURES? My research is closely related to CPs 1 and 2 of the STRUCTURES cluster. I also work very closely with Matthias Bartelmann and his group, where we further develop the KFT formalism. Recently, I have been elected as speaker for the STRUCTURES YRC.

What was your greatest scientific success up to now? I would say that contributing to the development of KFT and applying this new framework to a non-cosmological setting is my greatest scientific success so far.

How does one recognize you? I guess that would be by my laugh, which is very distinct and can be heard throughout Philosophenweg 12 (although some people claim it can be heard throughout Heidelberg).

Interview with Wilhelm Kroschinsky:



Wilhelm Kroschinsky
PhD Student, AG Marchetti, University of São Paulo, Brazil

What are you working on? In the last years, I have been working mostly on the so-called Majorant Method for fermions, which was proposed in the late 80s as a tool to do estimates on the irrelevant parts of the effective action in studies of the renormalization group. My group is now applying these techniques to a first concrete physical model.

What is your connection to STRUCTURES? I am spending 6 months of my PhD as an exchange student at STRUCTURES. My supervisor here is Prof. Manfred Salmhofer.

What was your greatest scientific success up to now? In my masters, I helped to prove that the lower bound of the interaction energy of a 2D system composed by an odd number of charged particles interacting via the (regularized) Yukawa potential can be improved from N to N-1. This is expected to be an important step towards proving a conjecture stated in the 80s which claims that the Mayer series associated to this system is convergent in a certain temperature range provided a few first terms of this series are removed.

How does one recognize you? If I am not at my office, I'm probably at the nearest Starbucks!

STRUCTURES ON THE WEB
https://structures.uni-heidelberg.de

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