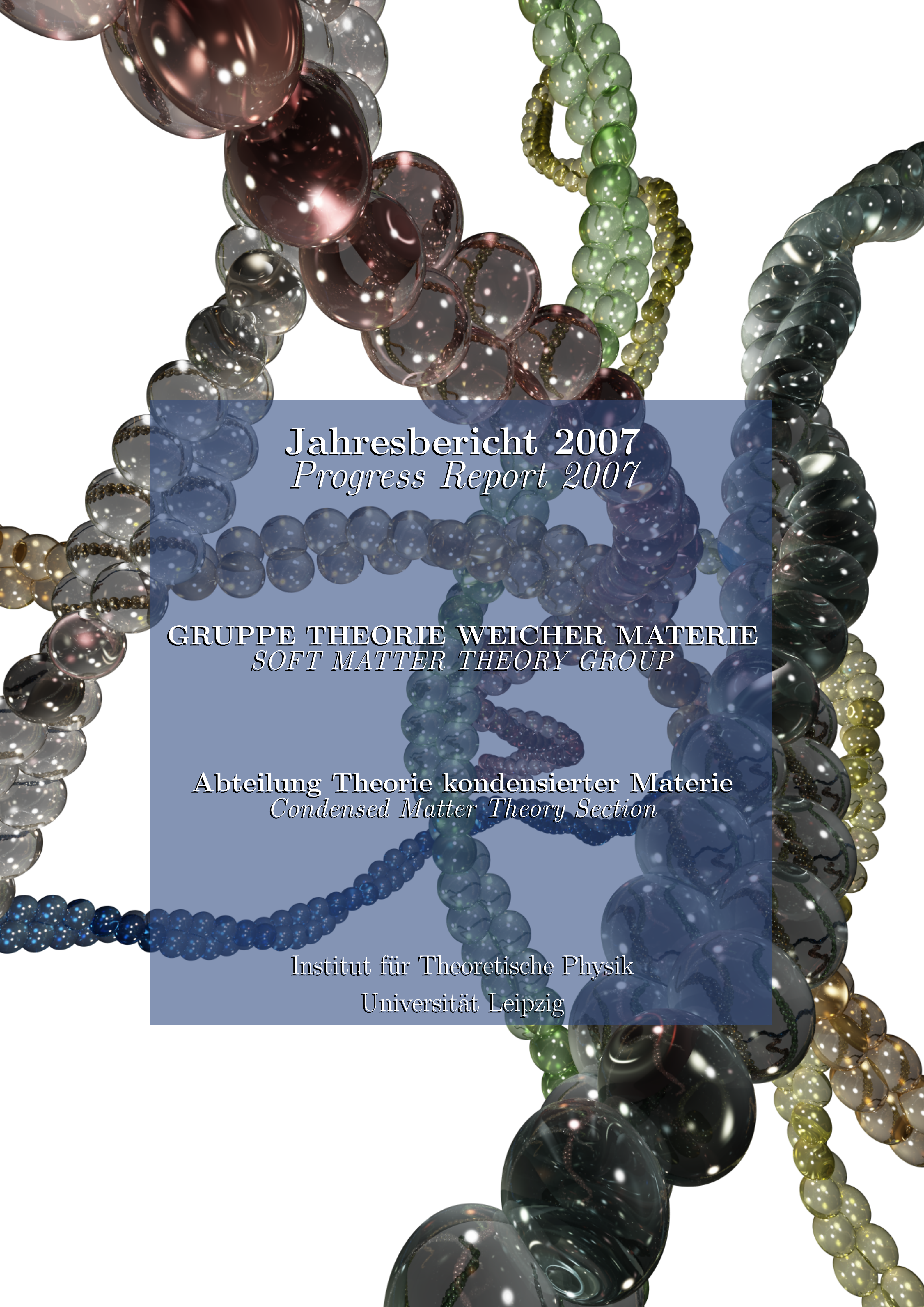

Jahresbericht 2007

Progress Report 2007

GRUPPE THEORIE WEICHER MATERIE

SOFT MATTER THEORY GROUP

Abteilung Theorie kondensierter Materie

Condensed Matter Theory Section

Institut für Theoretische Physik

Universität Leipzig

Author: Daniel Rings, daniel.rings@itp.uni-leipzig.de

Cover picture: Artistic conception of actin filaments. The similarity of the monomers to glass beads is intentional: In “Glass transition and rheological redundancy in f-actin solutions” (PNAS 2007), we report the observation of a glass transition in a semidilute solution of F-actin. Our results highlight the relation between F-actin and glassy mechanics of cells and tissues.

Das Jahr 2007

The year 2007

2007 was a particularly successful year for the group. We could welcome two visiting scientists, Dr. Pablo Fernandez and Dr. Abigail Klopper, who provided very stimulating input, and five new students, Steffen Grosser, Marcel Hennes, Christian Hubert, Andrea Kramer, and Sebastian Sturm.

Funding improved substantially thanks to the establishment of the group grant "Sächsische Forschergruppe" FOR877, where we pursue a joint project with the groups of Prof. F. Kremer and Dr. U. Keyser, and our participation in the successful proposal for a graduate school "Leipzig School of Natural Sciences – Building with Molecules and Nanoobjects (BuildMoNa)" within the German excellence initiative. Our scientific activities were rewarded with the opportunity to contribute the title page of the Christmas issue of PNAS.

Klaus Kroy

Contents

1 Gruppenstruktur

Group structure

1.1 Mitarbeiter

Members

- Prof. Dr. Klaus Kroy,
  Universität Leipzig, ITP-1R14, Tel. 0341 9732436
- Dipl.-Phys. Jens Glaser,
  Universität Leipzig, Linnéstr. 5 - 491, Tel. 0341 9732408
- Steffen Grosser,
  Universität Leipzig, Linnéstr. 5 - 491, Tel. 0341 9732408
- Marcel Hennes,
  Universität Leipzig, Linnéstr. 5 - 491, Tel. 0341 9732408
- Christian Hubert,
  Universität Leipzig, Linnéstr. 5 - 496, Tel. 0341 9732496
- Andrea Kramer,
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- Dipl.-Phys. Daniel Rings,
  Universität Leipzig, Linnéstr. 5 - 487, Tel. 0341 9732610
- Sebastian Schöbl,
  Universität Leipzig, Linnéstr. 5 - 487, Tel. 0341 9732610
- Sebastian Sturm,
  Universität Leipzig, Linnéstr. 5 - 487, Tel. 0341 9732610

1.2 Gastwissenschaftler

Visiting Scientists

- Dr. Pablo Fernandez,
  Universität Bayreuth, Lehrstuhl Experimentalphysik I,
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- Dr. Abigail Klopper,
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  01187 Dresden, Tel. 0351 8711118
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2 Projekte

Projects

Contents

2.1 Glassy dynamics of semiflexible polymer solutions

Jens Glaser, Christian Hubert, Klaus Kroy

We investigated the dynamical properties of solutions of semiflexible polymers. The starting point of our theoretical description is the wormlike chain (WLC), describing the dynamics of a semiflexible (weakly bending) polymer in solution. While this model is appropriate for isolated polymers, our approach was to modify the WLC in order to take into account cageing effects due to the surrounding polymer solution.

The key to the new description, called the "glassy wormlike chain" (GWLC) is an exponential stretching of the (long time) relaxation spectrum of an ordinary WLC. It is traced back to the activated relaxation of the transverse undulations over energy barriers, quantified by the stretching parameter $\mathcal{E}$ giving the height of the energy barriers [1] in units of $k_B T$. The predicted dynamic structure factor excellently fits experimental data, in particular the logarithmic tails observed in DLS [2]. The predictions for the (linear) shear moduli also agree very well with microrheological data for live cells [3].

The theory also predicts a nonlinear shear modulus, which was found to resemble the differential modulus measured for F-actin solutions [2]. It will be the next step to classify the contributions of physiological parameters to the stretching parameter $\mathcal{E}$. For instance, a temperature dependence of the shear modulus has been observed. On the other hand, it is known that metabolism rates in animals is temperature-dependent, too. A possible correspondence between these two phenomena is studied in terms of our theory. Extensions of the GWLC theory in several directions are possible, e. g. to semiflexible polymer bundles.

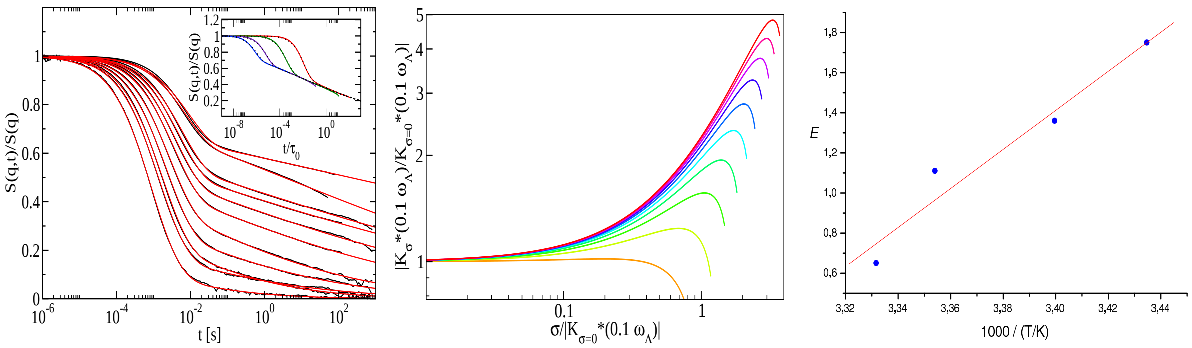


Figure 1: Left: Dynamic structure factor measured by DLS for several values of the scattering vector (black), red lines are theoretical fits. Center: Strain hardening and softening as predicted by the nonlinear modulus of the GWLC. Right: Temperature-dependence of the model parameter $\mathcal{E}$ obtained from fits of K_σ to experimental data from actin solutions.

References

[1] K. Kroy and J. Glaser. The glassy wormlike chain. *New J. Phys.*, 9 (416), 2007.

[2] C. Semmrich, T. Storz, J. Glaser, R. Merkel, A. R. Bausch, and K. Kroy. Glass transition and rheological redundancy in f-actin solutions. *Proc. Natl. Acad. Sci. USA*, 104(52):20199–20203, 2007.

[3] B. Fabry, G.N. Maksym, J.P. Butler, M. Glogauer, D. Navajas, and J.J. Fredberg. Scaling the microrheology of living cells. *Phys. Rev. Lett.*, 87(14):148102, 2001.

2.2 A microscopic approach to the nonlinear rheology of biopolymer solutions

Steffen Grosser, Pablo Fernandez, Klaus Kroy

We consider a simple unit-cell approach to model the nonlinear response of semidilute solutions of semiflexible polymers (for example actin) to external shear stress. The model, which was created by Pablo Fernandez and Klaus Kroy, considers only freely slipping polymers. In this project, we want to overcome this restriction.

The unit-cell is one segment of a polymer for which the deformation resulting from shear is calculated for affine background deformations. This segment is taken as representative of the whole network. The exact solutions of nonlinear elastic bending are used. To the bending term we add a confinement energy term according to the tube model for semiflexible polymers. This is a simple method to take fluctuations and non-trivial correlations (entanglements) of the polymers approximately into account. The results of such an approach are considerably different from pure enthalpic bending rod models.

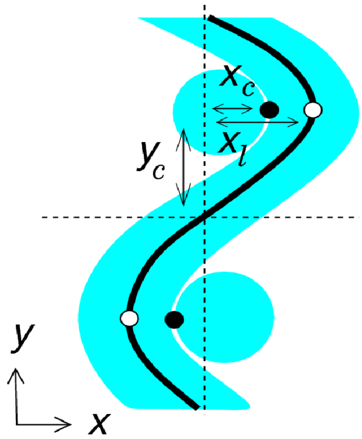
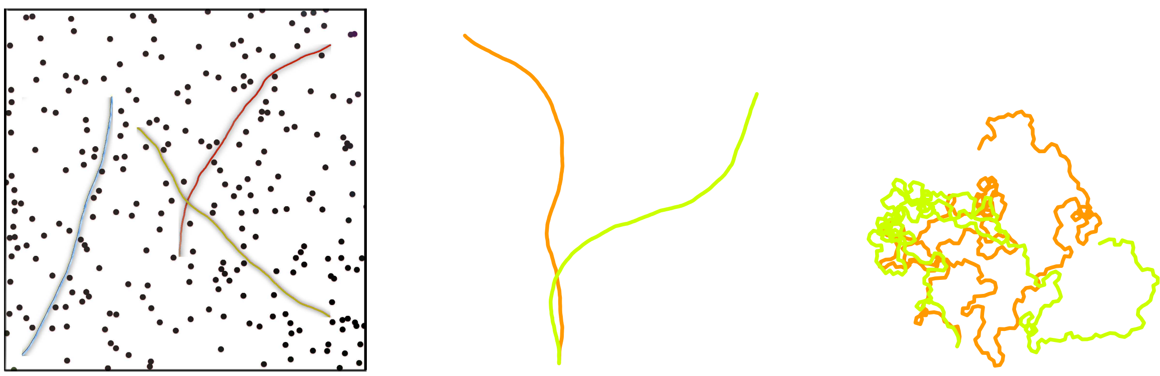


Figure 2: Under shear, a polymer (black line) and his thermal tube are distorted by the surrounding polymers

2.3 Impact of disorder on flocculation and semiflexible polymer conformations

Abigail Klopper, Sebastian Schöbl, Klaus Kroy

Cellular function is intimately connected with the mechanical and dynamical properties of an underlying cytoskeletal structure, which can be described as a random network of stiff polymers. One attempt to understand this relationship involves determining how these properties are influenced by the conformational statistics of single polymers within the network. This calls for shrewd modeling of the polymers' immediate environment - capturing the spatial confinement caused by cellular crowding within a simplified theoretical framework. In this spirit, the problem may be recast in terms of a wormlike chain embedded within a matrix of quenched random obstacles. Despite the prolific attention paid to the analogous problem in flexible polymer networks in recent years, little is understood about how their stiffer counterparts respond to such an environment. This can be partly attributed to the difficulties encountered when stiffness and inextensibility criteria are imposed simultaneously with quenched disorder constraints. With the view to circumvent these problems, we follow two strains of investigation: (i) we use a weakly bending rod formalism and employ replica theory to calculate disorder-averaged equilibrium properties of a stiff biopolymer in a quenched random environment, and (ii) we perform Monte Carlo simulations to determine these properties numerically in various kinds of random potentials, which are designed to mimic the interactions with the polymer network.



(a) semiflexible polymers in hard sphere background potential

(b) free semiflexible polymer chain conformations with $\xi = 2L$

(c) polymer chain configurations in Gaussian white noise potential

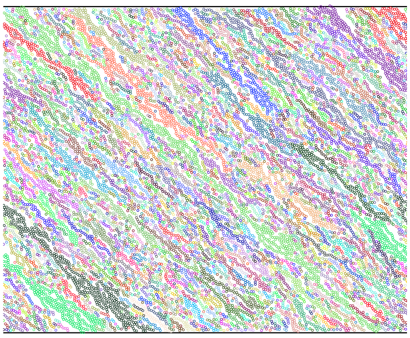
Figure 3: The illustrated conformations of semiflexible polymers found by Monte-Carlo simulations demonstrate the impact of disorder.

2.4 Colloidal Aggregation

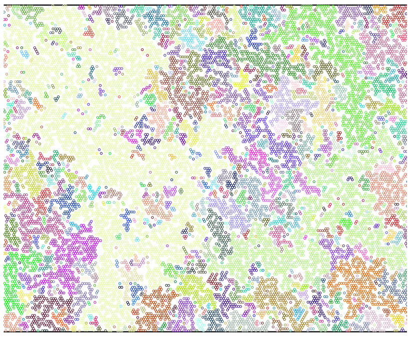
Daniel Rings, Sebastian Schöbl, Klaus Kroy

Aggregation of colloids has an impact on various technological as well as biological systems. In the framework of our toy model we study irreversible aggregation of a two-dimensional colloidal suspension under shear.

We optimized our collision-driven algorithm based on hierarchical coarse-graining of cluster structures in space and the exact prediction of the hard disk trajectories. Thus, it allows a systematic investigation of the sol-gel transition for a broad range of particle concentrations, and especially different initial packing structures (on-lattice, fluid-like). We find a high sensitivity in the time to gelation and in structural properties of the largest clusters to initial conditions. In particular, for hard-disk fluid initial conditions, the system seems to escape the expected crossover of driven cluster aggregation to the percolation universality class.



(a) A hard disk fluid, when suddenly quenched to adhesive interactions, develops clusters under shear. At high densities, these take an essentially linear form and become oriented along the compression axis, and the longest span the whole system in the shear gradient direction.



(b) Clusters grow quite isotropically and much more rapidly when a randomly occupied lattice is sheared. Spanning clusters have structural properties very similar to those of animal percolation clusters.

Figure 4: Snapshots of two systems at total occupied area fraction $\phi = 0.4$, but which have evolved from different initial configurations.

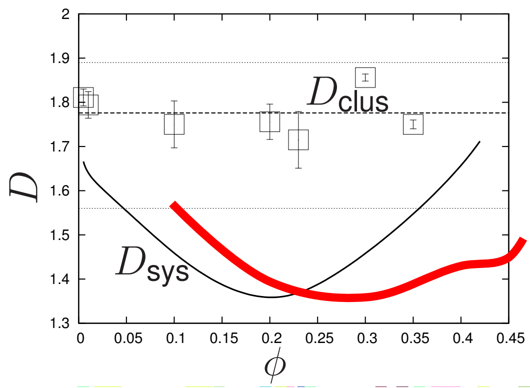


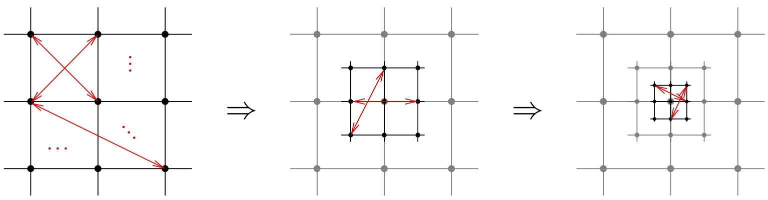
Figure 5: Starting from fluid structure, the “stringy” (low D) phase persists also at high densities (red line). This shows that the percolation universality class is broken in the absence of pre-formed clusters in shear driven flocculation.

2.5 Inertial particles in spatio-temporally correlated random flows

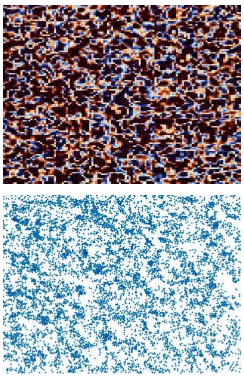
Daniel Rings, Klaus Kroy

The dynamics of inertial particles in fluctuating flow fields is of great interest in a broad spectrum of research ranging from transport processes in sand beds [1] over initiation of rainfall [2] to structure formation in complex plasma [3]. Macroscopic phenomena such as aggregation and pattern formation intimately depend on the fluctuations' characteristics in terms of spatial and temporal correlations, and on hydrodynamic particle features. While the sensitivity of particle dynamics on shape parameters of the underlying isotropically correlated random flow has been illustrated recently (by Mehlig *et al.* [4]), we are investigating the system's response to systematic changes in the correlation structure. With the aim of stochastic numeric simulations, we are pursuing to model and comprehend observations from the examples given above, especially the emergence of density waves in plasma and the presumably very similar rippling of granular surfaces under appropriate conditions.

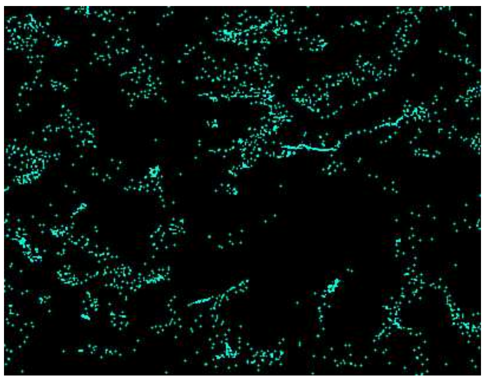
We use *multi-level* $(N \times N)$*-grid* field generation, i. e. point correlation matrices are calculated on p different length scales which allows for various correlation lengths $\xi_{0,\ldots,p-1}$, providing means to resemble multi-scale flows.



Preliminary Results: Structure formation



Plot of flow field (1st), and particles at consecutive time steps, $m = 0.4$, $\gamma = 0.4$, $k = 0.3$, $\mathrm{Cov}(\boldsymbol{r}) = 2.0 \cdot \exp(-\frac{|\boldsymbol{r}|}{0.04})$



Quasi-stationary state, same parameters except $m = 0.2$.

References

[1] Sauermann, G. *et al.*, Phys. Rev. E **64**, 031305 (2001)

[2] Wilkinson, M. *et al.*, Phys. Rev. Lett. **97**, 048501 (2006)

[3] Schwabe, M. *et al.*, (2007, unpublished)

[4] see e. g. Mehlig *et al.*, Phys. Rev. E **72**, 051104 (2005)

3 Veröffentlichungen
Publications

Tension dynamics in semiflexible polymers. I. Coarse-grained equations of motion

Oskar Hallatschek[1], Erwin Frey[2] and Klaus Kroy[3]
[1] Lyman Laboratory of Physics, Harvard University, Cambridge, Massachusetts 02138, USA
[2] Arnold Sommerfeld Center for Theoretical Physics and Center for NanoScience, LMU München, Theresienstrasse 37, 800333 München, Germany
[3] Institut für Theoretische Physik, Universität Leipzig, Augustusplatz 10/11, 04109 Leipzig, Germany

Phys. Rev. E 75 (2007) 031905

Based on the wormlike chain model, a coarse-grained description of the nonlinear dynamics of a weakly bending semiflexible polymer is developed. By means of a multiple-scale perturbation analysis, a length-scale separation inherent to the weakly bending limit is exploited to reveal the deterministic nature of the spatiotemporal relaxation of the backbone tension and to deduce the corresponding coarse-grained equation of motion. From this partial integro-differential equation, some detailed analytical predictions for the nonlinear response of a weakly bending polymer are derived in an accompanying paper [O. Hallatschek et al., following paper, Phys. Rev. E 75, 031906 (2007)].

Tension dynamics in semiflexible polymers. II. Scaling solutions and applications

Oskar Hallatschek[1], Erwin Frey[2] and Klaus Kroy[3]
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[3] Institut für Theoretische Physik, Universität Leipzig, Augustusplatz 10/11, 04109 Leipzig, Germany

Phys. Rev. E 75 (2007) 031906

In part I [O. Hallatschek et al., preceding paper, Phys. Rev. E 75, 031905 (2007)] of this contribution, a systematic coarse-grained description of the dynamics of a weakly bending semiflexible polymer was developed. Here, we discuss analytical solutions of the established deterministic partial integro-differential equation for the spatiotemporal relaxation of the backbone tension. For prototypal experimental situations, such as the sudden application or release of a strong external pulling force, it is demonstrated that the tensile dynamics reflects the self-affine conformational fluctuation spectrum in a variety of intermediate asymptotic power laws. Detailed and explicit analytical predictions for the tension propagation and relaxation and corresponding results for common observables, such as the end-to-end distance, are obtained.

Stretching dynamics of semiflexible polymers

Benedikt Obermayer[1], Oskar Hallatschek[2], Erwin Frey[1] and Klaus Kroy[3]
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Europ. Phys. J. E, 23 (2007) 375-388

We analyze the nonequilibrium dynamics of single inextensible semiflexible biopolymers as stretching forces are applied at the ends. Based on different (contradicting) heuristic arguments, various scaling laws have been proposed for the propagation speed of the backbone tension which is induced in response to stretching. Here, we employ a newly developed unified theory to systematically substantiate, restrict, and extend these approaches. Introducing the practically relevant scenario of a chain equilibrated under some prestretching force f_{pre} that is suddenly exposed to a different external force f_{ext} at the ends, we give a concise physical explanation of the underlying relaxation processes by means of an intuitive blob picture. We discuss the corresponding intermediate asymptotics, derive results for experimentally relevant observables, and support our conclusions by numerical solutions of the coarse-grained equations of motion for the tension.

The glassy wormlike chain

Klaus Kroy and Jens Glaser
Institut für Theoretische Physik, Universität Leipzig, Augustusplatz 10/11, 04109 Leipzig, Germany

New J. Phys. 9 (2007) 416

We introduce a new model for the dynamics of a wormlike chain (WLC) in an environment that gives rise to a rough free energy landscape, which we name the glassy WLC. It is obtained from the common WLC by an exponential stretching of the relaxation spectrum of its long-wavelength eigenmodes, controlled by a single parameter $\mathcal{E}$. Predictions for pertinent observables such as the dynamic structure factor and the microrheological susceptibility exhibit the characteristics of soft glassy rheology and compare favorably with experimental data for reconstituted cytoskeletal networks and live cells. We speculate about the possible microscopic origin of the stretching, implications for the nonlinear rheology, and the potential physiological significance of our results.

Glass Transition and Rheological Redundancy in F-Actin Solutions

Christine Semmrich[1], Tobias Storz[1], Jens Glaser[2], Rudolf Merkel[3], Andreas R. Bausch[1], and Klaus Kroy[2]
[1] Lehrstuhl für Biophysik E22, Technische Universität München, James-Franck-Strasse, 85748 Garching, Germany
[2] Institut für Theoretische Physik, Universität Leipzig, Postfach 100920, 04009 Leipzig, Germany
[3] Institut für Bio- und Nanosysteme (IBN-4), Forschungszentrum Jülich, D-52425 Jülich, Germany

Proc. Natl. Acad. Sci. (USA), 104 (2007) 20199-20203

The unique mechanical performance of animal cells and tissues is attributed mostly to their internal biopolymer meshworks. Its perplexing universality and robustness against structural modifications by drugs and mutations is an enigma in cell biology and provides formidable challenges to materials science. Recent investigations could pinpoint highly universal patterns in the soft glassy rheology and nonlinear elasticity of cells and reconstituted networks. Here, we report observations of a glass transition in semidilute F-actin solutions, which could hold the key to a unified explanation of these phenomena.

Combining suitable rheological protocols with high-precision dynamic light scattering, we can establish a remarkable rheological redundancy and trace it back to a highly universal exponential stretching of the single-polymer relaxation spectrum of a "glassy wormlike chain." By exploiting the ensuing generalized time-temperature superposition principle, the time domain accessible to microrheometry can be extended by several orders of magnitude, thus opening promising new metrological opportunities.

Dynamics of Aeolian Sand Heaps and Dunes: The Influence of the Wind Strength

S. Fischer & K. Kroy

in Traffic and Granular Flow '05, A. Schadschneider *et al.* (eds.), Springer, Heidelberg (2007).

The so-called *minimal model* provides an efficient minimum mathematical description of aeolian sand dune formation based on turbulent boundary layer calculations and a mean-field like saltation model. It allows us to analyze the effect of environmental conditions – uncontrollable in the field – on the characteristic shapes of dunes systematically. While the previously studied stationary solutions obtained under periodic boundary conditions are "unphysical" in the sense that they correspond to unstable fixed points of the equations, the solutions for open boundary conditions are shown to be strongly constrained by the unstable manifolds of these fixed points. For morphological evolution under periodically (e.g. seasonally) changing wind conditions a rule of thumb emerges, saying that the shapes of comparatively small/large dunes are slaved by the unstable manifolds pertaining to the actual/time-averaged environmental conditions, respectively.

4 Vorträge und Poster

Talks and Posters

4.1 Eingeladene Vorträge auf Konferenzen und Tagungen

Invited Talks at Conferences and Workshops

- Workshop "Macromolecular Systems for NanoScience - Chemistry, Physics and Engineering Aspects" des Elitenetzwerks Bayern, Irsee, 6.-9.9.
  Klaus Kroy: *Wormlike and Glassy Wormlike Chains*

- Workshop "Soft Meets Hard", Lutherstadt Wittenberg, 13.-15.9.
  Klaus Kroy: *The Glassy Wormlike Chain*

- Workshop "Path Integrals", Dresden, 24.-28.9.
  Klaus Kroy: *Wormlike Chains in Disordered and Glassy Environments*

4.2 Eingeladene Vorträge an Forschungsinstituten

Invited Talks at Academic Institutions

- International Research Training Group, Humoldt Universität, Berlin, 1.6.
  Klaus Kroy: *Why is actin soft and why does this matter?*

- Cavendish Laboratory, Cambridge, 30.11.
  Klaus Kroy: *Wormlike and Glassy Wormlike Chains*

- DLR, Köln, 5.10.
  Klaus Kroy: *Dynamic Scaling of Desert Dunes*

4.3 Beiträge auf Konferenzen und Tagungen

Contributions at Conferences and Workshops

- DPG-Meeting, 26-30 March 2007, Regensburg
  Daniel Rings: *Jamming Transition in Two-Dimensional Shear-Driven Aggregation*
  Jens Glaser: *Dynamic light scattering of F-actin solutions* (poster)

- International Soft Matter Conference 2007, 1-4 October 2007, Aachen
  Klaus Kroy: *The Glassy Wormlike Chain*
  Pablo Fernandez: *Brave misfits - A microscopic approach to the nonlinear rheology of biopolymer solutions* (poster)
  Jens Glaser: *Glass transition and rheological redundancy in F-actin solutions* (poster)
  Abigail Klopper: *Semiflexible chains in disordered media* (poster)
  Pablo Fernandez: *Living cell mechanics: stress stiffening and kinematic hardening* (poster)
  Daniel Rings: *Influence of spatio-temporal correlations of random flows on inertial particle dynamics* (poster)

- 396. Wilhelm and Else Heraeus-Seminar: Nonlinear Dynamics, From small scales to coherent structures, 7-10 October 2007, Bayreuth
  Daniel Rings: *Influence of spatio-temporal correlations of random flows on inertial particle dynamics* (poster)

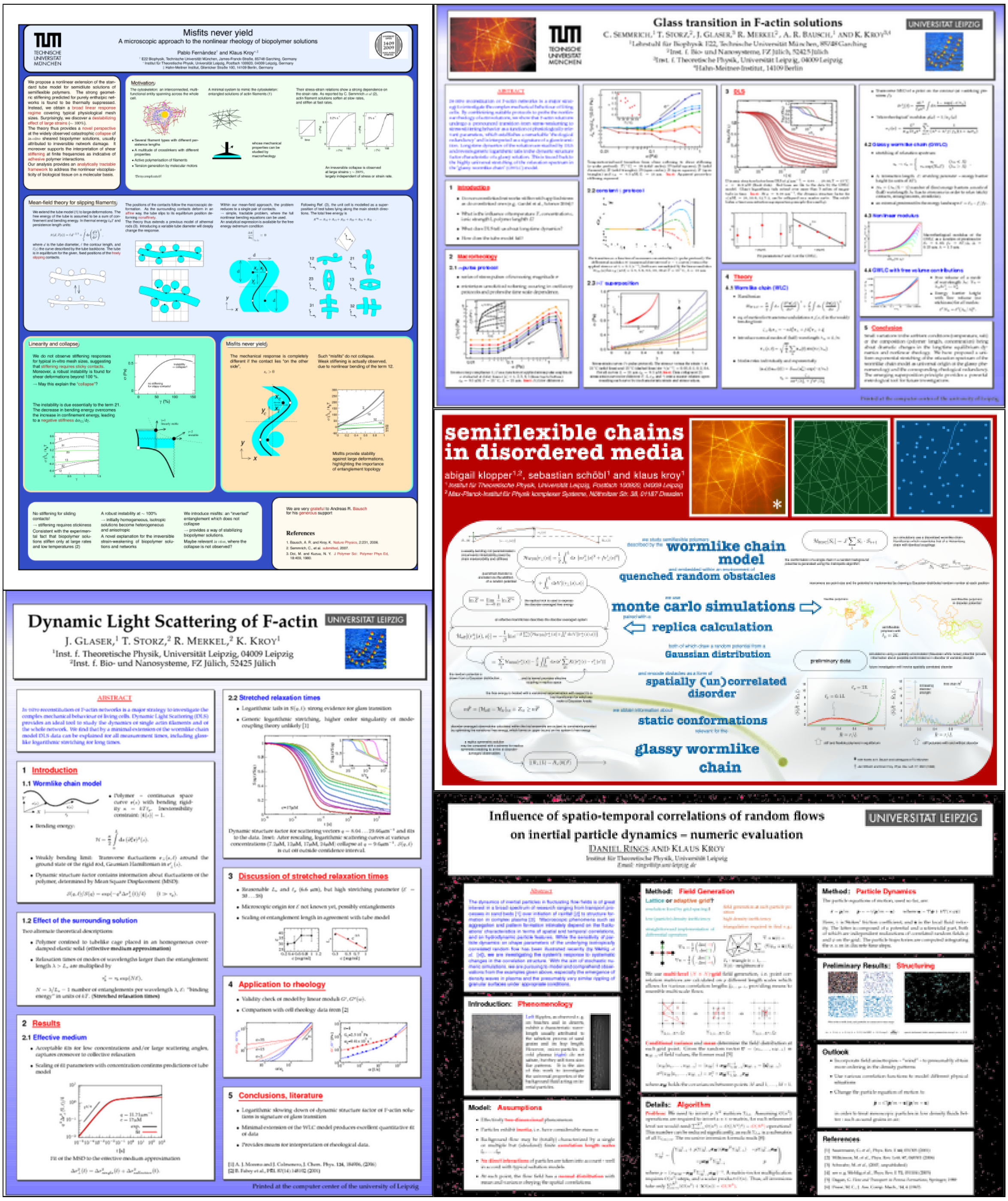

Table 1: Some thumbnails of posters and talks.

5 Vorlesungen

Lectures

5.1 SOSE 2007

Statistische Mechanik (Lehramt)

Kursvorlesung, Universität Leipzig

Die Vorlesung bietet eine Einführung in die Grundelemente der Thermodynamik und der Statistischen Mechanik. Zunächst werden die statistischen Gesamtheiten eingeführt und die Boltzmanngleichung abgeleitet. Es wird die Thermodynamik und der Zusammenhang der Ensembles gewonnen bevor im nächsten Abschnitt Fluktuationen und Responsekoeffizienten besprochen werden. Danach werden die vorgestellten Konzepte auf das Ising-Modell und ideale Quantengase angewandt, wobei sowohl Bose-Einstein-Kondensation als auch ein entartetes Fermigas sowie der klassische Grenzfall betrachtet werden.

Biophysics and Quantitative Biology

Lehrseminar, Universität Leipzig

Das Ziel diese Seminars war zum einen, essentielles Hintergrundwissen zu erlangen, um den aktuellen Debatten in der theoretischen Biologie und Biophysik beitreten zu können, und zum anderen, den Teilnehmern eine Möglichkeit zu geben, ihre Vortragsfertigkeiten zu trainieren. Dazu wurden die folgenden Themen vorgeschlagen:

Scaling in Biology; Small-World and Scale-Free Networks; Population Dynamics; Population Genetics; Game Theory (The Minority Game); Self-Propelled Particles; Swimming at low Reynolds Numbers; Systems Biology; Physics of DNA; Proteomics (Secondary Structure); Experimental Cell Biophysics; Percolation in Biology; TASEP;

5.2 WISE 2007/2008

Quantenmechanik (Lehramt)

Kursvorlesung, Universität Leipzig

Die Vorlesung bietet eine Einführung in die Grundelemente der Quantenmechanik. Ausgehend von der klassischen Mechanik wird die Schrödinger-Gleichung motiviert und der übliche Formalismus der Operatordarstellung in Impuls- und Ortsraum eingeführt. Neben verschiedenen eindimensionalen Potentialen werden Problemstellungen wie Doppelspalt-Experiment und Wasserstoffatom diskutiert und in Hausübungen vertieft.

Physics of Biopolymers. From Theory to Applications.

Wahlfach, Vorlesung (zus. mit U. Keyser), Universität Leipzig

Den meisten Physikern sind atomare oder molekulare Kristalle geläufig, aber die meisten Materialen, welche in modernen Technologien Verwendung finden oder mit denen wir alltäglich zu tun haben, fallen nicht in diese Kategorie. Stattdessen spielen Polymere eine große Rolle in Kunststoffen, Kosmetika, Nahrungsmitteln und Lebewesen. Was sind die universellen Eigenschaften solcher Makromoleküle, die von Polystyrol bis DNA reichen? Und wie werden diese experimentell untersucht und technologisch verwertet? Solche Fragen klassischer und moderner Probleme wurden theoretisch und experimentell beleuchtet.

6 Laufende Diplomarbeiten

Diploma Theses in Progress

- Steffen Grosser
  "Ein mikroskopischer Ansatz für die nichtlineare Rheologie von Biopolymerlösungen: Ziel ist, eine nichtlineare Kraft-Deformations-Abhängigkeit zu bestimmen. Dazu wird der Einfluss einer Scherung auf die Verformung und die Einschränkung der thermischen Bewegung eines semiflexiblen Polymers im Netzwerk betrachtet."

- Marcel Hennes
  "Cell Rheology and the Glassy Wormlike Chain"

- Christian Hubert
  "Temperatur und glasartige Dynamik in einfachen biologischen Modellsystemen"

- Sebastian Schöbl
  "Impact of Disorder on Flocculation and Semiflexible Polymer Conformations"

- Sebastian Sturm
  "Force propagation through the cytoskeleton"

7 Laufende Doktorarbeiten

PhD Theses in Progress

- Jens Glaser
  "Strukturuntersuchung von F-Aktin-Lösungen: In der Arbeit geht es um die Theorie der dynamischen Lichtstreuung an semiflexiblen Polymeren sowie kollektive Effekte von Lösungen semiflexibler Polymere"

- Daniel Rings
  "Dynamik granularer Medien im Strömungsfeld und Strukturbildung: Ausgehend von einer Beschreibung des Transportmechanismus von Medien wie z.B. Sand in turbulenter Strömung werden verschiedene Strukturen - Dünen, Rippel, Kaustiken - und ihre Dynamik untersucht"

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