The 7th Soft Matter Summer School : Soft Matter and Slow Relaxation Dynamics

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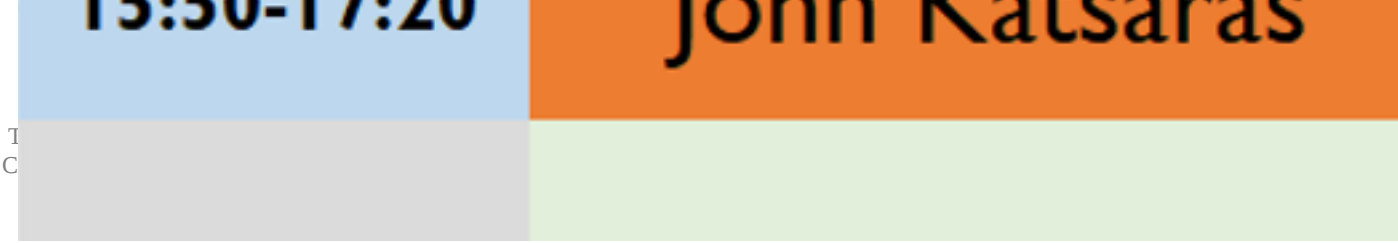
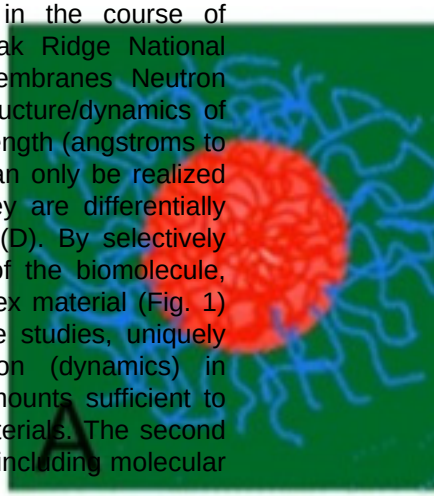
Conference Scientific Programme



List of Lectures: Alex Levine (University of California, Los Angeles) : Filaments with transient cross linkers: The condensation transition into bundles and glassy dynamics in bundle networks. In this lecture, I will report on recent work regarding the equilibrium phase behavior of stiff biopolymer filaments and cross linkers. I will show that, due to Casimir interactions, there is a first order condensation transition between free filaments and their bundles. The resulting networks of bundles show anomalous glassy rheology at low frequency. In addition to reporting on these results, I will review a few fundamental aspects of path integrals as their are used to describe the statistical mechanics of polymers and will briefly review rheology when discussing filament bundle networks. : Dynamics of undulations of curved manifolds: applications to understanding the spatial distribution of red blood cell fluctuations. In this lecture, I review the mechanics of undulatory waves on curved elastic manifolds, showing that these waves reflect and refract from changes in Gaussian curvature. I then use this analysis to predict the spatial distribution of undulations on red blood cells, which have been observed for over a century. As part of this lecture, I review the geometry of curved two-dimensional manifolds and discuss the coupling of in-plane and out-plane elasticity by local curvature. Time permitting, I discuss the implications of geometry for hydrodynamics on curved two-dimensional fluid membranes and discuss the implications for the diffusion of transmembrane proteins. Erez Braun (Technion) : Order from disorder in biological systems at different levels of organization Biological systems provide a prime example for naturally occurring complex, far from equilibrium, processes showing the emergence of order from the underlying microscopic disorder. The approach to this complexity reflects the tension between a reductionist, reverse engineering stance and the more abstract, systemic one attempting to uncover the organization principles underlying living matter. Our work challenges the ability to reverse engineer biological systems. In particular, it demonstrates the difficulty in identifying the relevant degrees of freedom underlying biological phenomena. We will explain the challenge, mainly concentrating on the microscopic-macroscopic degeneracy and the inherent difficulty in separating the dynamics at any given level of organization from the coupled dynamics of the other levels, including the environment within which the system is embedded. By discussing two examples from our recent experimental research, we will briefly sketch an alternative methodology to the programmatic, reverse engineering approach, based on exploratory self-organization dynamics. First, we will discuss the organization of cells leading to their well-defined morphology, metabolism and function. Cell-state organization is a dynamical process in which the genome does not determine the ordered cell state; rather, it participates in this process by providing a set of constraints on the spectrum of regulatory modes, analogous to boundary conditions in physical dynamical systems. We will demonstrate that the underlying physics of cell-state organization, in the context of a cell population, is based on exploratory dynamics allowing adaptation and convergence on physiological time scales in the high-dimensional variable space. Second, we will discuss morphogenesis—the emergence of form and function in a developing organism, which is one of the most remarkable examples of pattern formation in nature. We will focus on the dynamic interplay of three type of processes underlying morphogenesis: Biochemical, mechanical and electrical which span all scales from the molecular to the entire organism. We utilize Hydra, a small multicellular fresh-water animal exhibiting remarkable regeneration capabilities, as a model system to show that: **1.** Mechanical forces and feedback shape the body plan during morphogenesis. **2.** An external electric field above a critical value can lead to reversal of morphogenesis: a fully developed animal flows back into its incipient state, which nevertheless can regenerate again when the amplitude of the external electric field is reduced below criticality. Reversal of morphogenesis is demonstrated to result from enhanced electrical excitations of the Hydra tissue. Controlled reversal trajectories open a new vista on morphogenesis and suggest a novel approach to study the physical basis of regeneration. For each of these examples, we will first discuss the necessary background and then sketch the main experimental findings, followed by their implications and generalized conclusions. Lecture Note I Ralf Everaers (École normale supérieure de Lyon) : The physics of entangled and untangled polymer solutions: from tube models to territorial ring polymers and chromosomes Diffusing polymers can slide past each other, but their Brownian motion is subject to topological constraints, since the chain backbones cannot cross. In my lecture I will discuss consequences of this effect for Soft and Living Matter. In my first lecture, I will review the Rouse and the Edwards/de Gennes tube models of polymer dynamics and their explanation of how microscopic "entanglements" dominate the macroscopic viscoelastic behavior of polymer liquids.

Furthermore, I will introduce the Kremer-Grest bead-spring model and computational techniques used for simulating these generic model systems. The lecture focuses on two questions: 1) how can computer simulations be used to explore the physics underlying the tube model and 2) how should we model / think about chromosome folding in interphase nuclei, where reptation times far exceed biologically relevant times scales. In my second lecture, I will discuss the Statistical Physics of non-concatenated (untangled) ring polymers, which crumple and segregate in the melt state and which provide quantitative, non-trivial models for the large scale structure of interphase chromosomes. Furthermore, I will present results from a recent collaboration with experimental colleagues, where we have studied chromosome folding in Drosophila in the course of development from the fertilized egg to the embryo. John Katsaras (Oak Ridge National Laboratory) : Static and Dynamic Neutrons Scattering from Biological Membranes Neutron scattering are nondestructive and label-free techniques used to study the structure/dynamics of hydrogen-rich materials (e.g., biological membranes) over extended scales of length (angstroms to microns) and time (picoseconds to milliseconds). However, their full power can only be realized with the availability of selectively deuterated samples – this is because they are differentially sensitive to hydrogen's stable isotopes, namely protium (H) and deuterium (D). By selectively substituting D for H, either in the solvent or explicitly in chemical groups of the biomolecule, contrast can be used to make "visible" or "invisible" specific parts of a complex material (Fig. 1) without altering its chemistry. Deuteration thus enables otherwise impossible studies, uniquely revealing relationships between molecular structure (static) and function (dynamics) in biomembranes. The first lecture will detail how neutrons are produced in amounts sufficient to carry-out scattering experiments and scattering theory as it relates to soft materials. The second lecture will describe recent examples how we have used neutrons and X-rays, including molecular dynamics simulations, to address the structure and dynamics of membranes.



contrast of polymeric micelle. (A) No contrast matching. (B) Corona matched to solvent. (C) Core matched to solvent. Hajime Tanaka (University of Tokyo) : Viscoelastic phase separation Phase separation is one of the most fundamental phenomena that create spatially inhomogeneous patterns in materials and nature. It has so far been classified into three types: (i) solid, (ii) fluid, and (iii) viscoelastic phase separation [1]. The relevant transport processes are only diffusion for (i), diffusion and hydrodynamic convection for (ii), and diffusion, hydrodynamic convection, and mechanical stress for (iii). Here we discuss the physical mechanism of viscoelastic phase separation. This phase separation takes place universally if there is strong dynamic asymmetry between the components of a mixture. The origin of the dynamic asymmetry is either the size disparity between the components or the difference in the glass transition temperature between the components. For example, viscoelastic phase separation has been observed in polymer solutions, protein solutions [2], colloidal suspensions [3], and membrane systems [4]. Under a deep quench, a transient gel is formed by strong attractive interactions between the slower components. The connectivity of the network acts against phase separation and produces the mechanical stress in it. The coupling between the composition, velocity, and stress fields is the key to this phase separation. We also find phase-separation behaviour accompanying mechanical fracture [5]. Surprisingly, mechanical fracture becomes a dominant coarsening process of the phase separation. The behaviour of viscoelastic and fracture phase separation originates from a strong coupling between the composition and deformation field. We demonstrate that the same type of coupling between the density and deformation field leads to cavitation of fluid under shear and mechanical fracture of glassy liquids and solids under deformation [6]. We discuss a common physics underlying these apparently unrelated phenomena and a selection principle of the kinetic pathway of pattern evolution. For example, the only difference between phase separation and fracture may stem from whether deformation is produced internally by phase separation itself or externally by loading. (The author thanks T. Araki, T. Koyama, Y. Nishikawa, and Y. Iwashita, and M. Tateno, for collaboration on viscoelastic phase separation and A. Furukawa for collaboration on cavitation and fracture. This work was partly supported by a Grant-in-Aid for Scientific Research from JSPS.) [1] H. Tanaka, J. Phys.: Condens. Matter **12**, R207 (2000)■H. Tanaka and T. Araki, Chem. Eng. Sci. **61**, 2108 (2006); H. Tanaka, Faraday Discuss. **158**, 371 (2012); "Phase Separation in Soft Matter: The Concept of Dynamic Asymmetry", vol. Soft Interfaces of Session XCVIII, École de Physique des Houches, Ch. 15, 465–526 (Oxford University Press, Oxford, 2017); T. Koyama and H. Tanaka, Phys. Rev. E **98**, 062617 (2018). [2] H. Tanaka and Y. Nishikawa, Phys. Rev. Lett. **95**, 078103 (2005). [3] H. Tanaka, Y. Nishikawa and T. Koyama, J. Phys.

Condens. Matter **17**, L143 (2005); M. Tateno and H. Tanaka, npj Comput. Mater. **5**, 40 (2019); in preparation. [4] Y. Iwashita and H. Tanaka, Nat. Mater. **5**, 147 (2006). [5] T. Koyama, T. Araki and H. Tanaka, Phys. Rev. Lett. **102**, 065701 (2009). [6] A. Furukawa and H. Tanaka, Nature **443**, 434 (2006); Nature Mater. **8**, 601 (2009). Vincenzo Vitelli (University of Chicago) : Odd elasticity of chiral active solids Hooke's law states that the deformations or strains experienced by an elastic object are proportional to the applied forces or stresses. The number of coefficients of proportionality between stress and strain, i.e. the elastic moduli, is constrained by energy conservation. In this talk, we generalize continuum elasticity to active media with non-conservative (or non-reciprocal) microscopic interactions. This generalization, which we dub odd elasticity, reveals that two additional elastic moduli can exist in a two-dimensional isotropic solid with strain dependent activity. Such an odd-elastic solid can be regarded as a distributed engine: work is locally extracted, or injected, during quasi-static cycles of deformation. By coarse graining illustrative microscopic models, we show how odd elasticity emerges in active metamaterials composed of springs that actuate internal torques in response to strain. Our predictions, corroborated by simulations, uncover phenomena ranging from activity-induced auxetic behavior to wave propagation powered by self-sustained active elastic cycles in non-Hermitian mechanical systems. Tsvi Tlusty (Institute for Basic Science/ Ulsan National Institute of Science and Technology) : The Mechanics of Evolution The links between the mechanics of biomolecules and their evolution will be discussed within simple physical models. Our main example will be the protein. Proteins are a matter of dual nature. As a physical object, a protein molecule is a folded chain of amino acids with multifarious biochemistry. But it is also an instantiation along an evolutionary trajectory determined by its function. Theories of proteins therefore need to examine both aspects, the biophysical and the evolutionary. Specifically, they need to explain how the DNA gene is mapped into the functional phenotype of the protein. We will review several physical approaches to the protein problem, focusing on a mechanical framework which treats proteins as evolvable condensed matter. Alexander Grosberg (New York University) :Topological Constraints in Passive and Active Dynamics of Polymers and Biopolymers Topological constraints in polymers arise from the simple fact that two chains or two parts of the same chain cannot pass through one another (unless special enzymes are used in case of DNA). This leads to the surprisingly rich set of consequences. In the lectures, we will start by reminding of basic concepts from polymer topology and then continue towards classical reptation theory followed by more recent developments in the passive and active nanorheology of polymeric systems, with an eye on aplicatioons to the physics of chromatin. Changbong Hyeon (Korea Institute of Advanced Study) :Slow dynamics in biological processes. Biological processes are characterized with many different time scales, which could be deemed to occur in complex free energy landscapes. After surveying various rate processes and their basics, I will talk about the followings as interesting examples in slow dynamics in biological processes. (1) "Expanding sausage model" by de Gennes will be reviewed to discuss the relaxation dynamics of (bio)polymer. (2) Quenched and dynamic disorders will be discussed in the context of ligand binding to a receptor. (3) I will discuss broken ergodicity, and give a few examples of its manifestation in biological processes. Georg Maret (University of Konstanz) : Functional Brain Imaging based on Diffusing Wave Spectroscopy and Ultrasound Dynamic multiple light scattering, also known as Diffusing Wave Spectroscopy, has found many useful biomedical in vivo applications recently because of its extreme sensitivity to small displacements of scatterers in living tissue. After a tutorial introduction of the underlying physical principles this talk focuses on the development of multichannel DWS to non-invasively probe and image neural activity and its changes due to external stimuli. Examples include the search for neural response patterns due to stimuli by magnetic fields comparable to the earth´s field in order to pinpoint the illusive mechanism of magnetoreception in homing pigeons. The intrinsically poor space resolution of DWS imaging is overcome by high frequency plane wave Doppler ultrasound imaging which provides 3D real time movies of functional response patterns with resolution down to 100 microns. Bo Li (Institute for Basic Science) : Surprises in non-equilibrium systems, from colloidal glass to epithelial cells Almost all processes found in nature are not in thermodynamic equilibrium, for they are work in progress rather than established edifice, and are subject to flux of energy or to intriguing chemical/biological signal pathways. Consequently, surprises emerge in non-equilibrium systems on different length scales and in both structural and dynamical aspects. Here I present experimental studies that challenge the paradigm on the relaxation and migration behaviors in two distinct non-equilibrium systems. In the first experiment,

we drove the colloidal glasses out of equilibrium by highly focused laser pulses and probed the response of the system afterwards. We identi■ed a non-monotonic dynamical length scale as a function of area fraction, resulting from the fractal relaxation patterns in high density regime. In the second experiment, we investigated the migration of confluent epithelial cells in confined geometry. Confronting the narrowing passage, the cell colony exhibited a smart group strategy of shrinkage in the direction perpendicular to the channel, for the sake of accelerating the migration. At the same time, the expression of F-actin first enhanced at the shrinking edge and then propagated inside; implying force sensing and feedback at single cell level during the migration. Our experiments highlight how the complexity of the building blocks and their interplay with the environments lead to exotic collective behaviors in non-equilibrium systems.