Symposium Anomalous Transport in Heterogeneous Media - from Porous Materials to Cellular Crowding (SYAT)

jointly organized by
the Biological Physics Division (BP),
the Dynamics and Statistical Physics Division (DY),
the Chemical and Polymer Physics Division (CPP), and
the Metal and Material Physics Division (MM)

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Overview of Invited Talks and Sessions

(lecture room H1)

Invited Talks

SYAT 1.1	Wed	14:30–15:00	H1	**Aging, ergodicity breaking and universal fluctuations in continuous time random walks: Theory and (possible) experimental manifestations** — •Igor Sokolov
SYAT 1.2	Wed	15:00–15:30	H1	**Distinguishing anomalous from simple diffusion in crowded solutions and in cells with fluorescence correlation spectroscopy** — •Cecile Fradin, Daniel Banks, Shyemaa Shehata, Felix Wong, Robert Peters
SYAT 1.3	Wed	15:30–16:00	H1	**Exploring Diffusion in Nanostructured Systems with Single Molecule Probes: From Nanoporous Materials to Living Cells** — •Christoph Bräuchle
SYAT 2.1	Wed	16:30–17:00	H1	**The Lorentz model: a paradigm of anomalous transport** — •Felix Höfling
SYAT 2.2	Wed	17:00–17:30	H1	**Viscoelastic subdiffusion: from anomalous to normal** — •Igor Goychuk
SYAT 2.3	Wed	17:30–18:00	H1	**Phase transitions, liquid micro-compartments, and embryonic patterning** — •Clifford Brangwynne, Jöbin Gharakhani, Anthony Hyman, Frank Jülicher

Sessions

SYAT 1.1–1.3	Wed	14:30–16:00	H1	**Anomalous Transport in Heterogeneous Media I**
SYAT 2.1–2.3	Wed	16:30–18:00	H1	**Anomalous Transport in Heterogeneous Media II**

SYAT 1: Anomalous Transport in Heterogeneous Media I

Time: Wednesday 14:30–16:00 Location: H1

Invited Talk SYAT 1.1 Wed 14:30 H1

Aging, ergodicity breaking and universal fluctuations in continuous time random walks: Theory and (possible) experimental manifestations — •Igor Sokolov — Institut für Physik, Humboldt-Universität zu Berlin

We consider some peculiarities of subdiffusive transport within the continuous time random walk (CTRW) model as appearing in the mean-field description of particles' motion in random potentials (energetic disorder). The anomalous diffusion under CTRW is a process with non-stationary increments. This non-stationarity introduces explicit dependence of observables on the time elapsed from preparing the system in its present state, and corresponds to aging of the process. Aging leads to such unusual properties of the system's time evolution as death of linear response to an external stimulus or as intrinsic ergodicity breaking. The last can have different manifestations, like the explicit dependence of the moving time averages on the interval of averaging or like universal fluctuations in kinetic coefficients in different realizations of the process. These properties lead to several interesting effects, which are specific for energetic disorder and which can be used for distinguishing this mechanism of anomalous subdiffusion from other possible mechanisms (like the existence of slow modes or diffusion in geometrically disordered systems). We discuss how these properties were (or can be) used in interpretation of experimental or numerical findings, and also consider some cases of anomalous diffusion of mixed origin (e.g. involving geometric and energetic disorder at the same time).

Invited Talk SYAT 1.2 Wed 15:00 H1

Distinguishing anomalous from simple diffusion in crowded solutions and in cells with fluorescence correlation spectroscopy — •Cecile Fradin, Daniel Banks, Shyemaa Shehata, Felix Wong, and Robert Peters — Dept. of Physics and Astronomy, McMaster University, Hamilton, Canada

The diffusion of proteins in cells is at the core of many important biological processes, in particular signal transduction and pattern formation. Yet, whether and why protein diffusion in cells may deviate from simple diffusion remains a matter of debate. One model often proposed to explain the experimental results is that this diffusion is anomalous, where the mean-squared displacement of the particles scales with time as $\sim t^{\alpha}$ (instead of $\sim t$ for simple diffusion). It has often been suggested that anomalous diffusion could arise due to the crowding of the cellular environment. To test this hypothesis, we have performed variable length scale fluorescence correlation spectroscopy experiments, where the size of the detection area was varied, allowing to check whether the apparent diffusion coefficient varied with the scale of observation, a non-ambiguous indication of anomalous behavior. In cross-linked gels, we observed as expected that the diffusion of tracer particles was anomalous. In crowded polymer solutions and in live C. elegans embryos, on the other hand, and although single length scale fluorescence correlation spectroscopy experiments point to a strong anomalous behavior, variable length scale analysis failed to detect anomalous diffusion.

Invited Talk SYAT 1.3 Wed 15:30 H1

Exploring Diffusion in Nanostructured Systems with Single Molecule Probes: From Nanoporous Materials to Living Cells — •Christoph Bräuchle — Department of Chemistry and Biochemistry and Center for Nanoscience (CeNS), LMU München, Butenandtstr. 11, D-81377 München/Germany

Molecular movement in confined spaces is of broad scientific and technological importance in areas ranging from molecular sieving and membrane separation to active transport along intracellular networks. Whereas measurements of ensemble diffusion provide information about the overall behaviour of the guests in a nanoporous host, tracking of individual molecules provides insight into both the heterogeneity and the mechanistic details of the molecular diffusion as well as into the structure of the host. Here we show how single dye molecules act as beacons while they diffuse through the different structural phases of the host. A unique combination of transmission electron microscopy and single molecule tracking reveals unprecedented details of the movement of a molecule, how it varies its mobility and bounces off a domain boundary or travels through various defect structures and adsorption sites. Furthermore, investigations of the uptake and trafficking of artificial viruses in living cells will show three different phases of mobility of these nanoparticles during their transfection pathway into a living cell.

SYAT 2: Anomalous Transport in Heterogeneous Media II

Time: Wednesday 16:30–18:00 Location: H1

Invited Talk SYAT 2.1 Wed 16:30 H1

The Lorentz model: a paradigm of anomalous transport — •Felix Höfling — Rudolf Peierls Centre f. Theoretical Physics, University of Oxford, 1 Keble Road, Oxford OX1 3NP, United Kingdom

Transport in spatially heterogeneous materials such as rocks, soils, gels, and ceramics is strongly hindered and often anomalously slow. Subdiffusive motion is found further in cell membranes and in the cytoplasm, which are densely packed with differently sized proteins, lipids, and sugars, summarised as macromolecular crowding.

The Lorentz model provides a simplistic model for transport in a spatially heterogeneous medium, the latter being represented by randomly distributed obstacles. Slow dynamics and anomalous transport emerge generically over the full range of packing fractions. A localisation transition induces subdiffusive motion, which is observed over many decades in time close to the critical point. The dynamics is rationalised in terms of a cluster-resolved scaling theory and characterised by a set of universal exponents.

A two-dimensional version of the Lorentz model is motivated by the subdiffusive motion of membrane proteins, which can be measured with fluorescence correlation spectroscopy (FCS). Based on FCS experiments *in silico*, it is shown that varying the beam waist of the illuminating laser reveals the intricate interplay of the heterogeneous medium and the anomalous transport. Going beyond the common assumption of spatially Gaussian transport, the analogy of FCS to other dynamic scattering methods is highlighted, establishing its potential of resolving complex dynamics in both space and time.

Invited Talk SYAT 2.2 Wed 17:00 H1

Viscoelastic subdiffusion: from anomalous to normal — •Igor Goychuk — Institut für Physik, Universität Augsburg, Germany

The subdiffusional search can bring certain advantages for the cell functioning. However, it can also entail fatal consequences by leading to vanishing effective rates of the subdiffusion-limited binding reactions. Yet there is an increasing body of evidence for the occurrence of subdiffusion in healthy biological cells. Which is the physical mechanism for it and why it can be beneficial? Different answers are currently given. I will discuss one physical mechanism based on the viscoelasticity of complex crowded media within a generalized Langevin equation description. It will be shown that: (i) this mechanism is ergodic, (ii) it does not entail a quasi-infinite mean residence time in a finite spatial domain, and therefore (iii) the subdiffusion-limited binding rate is finite. The escape kinetics out of a potential well follows asymptotically a stretched-exponential law. However, in the limit of high barriers it becomes ever more normal and described by the non-Markovian rate theory. This limit of exponential kinetics can be practically achievable or not, depending on the subdiffusion exponent, memory cutoff, potential height and temperature. Surprisingly, in periodic potentials such a viscoelastic subdiffusion is asymptotically not sensitive to the presence of potential. However, the transient regime with a slowly changing subdiffusion exponent can last very long and initially resemble normal diffusion. Such a combination of anomalous and normal features selects viscoelastic mechanism as biologically most relevant [1].

[1] I. Goychuk, Phys. Rev. E **80**, 046125 (2009).

Invited Talk SYAT 2.3 Wed 17:30 H1

Phase transitions, liquid micro-compartments, and embryonic patterning — •Clifford Brangwynne[1,2], Jöbin Gharakhani[1], Anthony Hyman[2], and Frank Jülicher[1] — [1]Max Planck Institute for the Physics of Complex Systems, Dresden, Germany — [2]Max Planck Institute for Molecular Cell Biology and Genetics, Dresden, Germany

Cells contain many RNA/protein micro-compartments that are not bound by membranes, such as germ granules, Cajal bodies, and nucleoli. How these structures assemble and disassemble, and what maintains their shape and structural integrity, are poorly understood. Here we focus on germ granules (P granules) in C.elegans embryos. In the 1-cell embryo, P granules are partitioned into one of the two daughter cells by an unknown mechanism. Using fluorescence imaging and 3D particle tracking, we find that P granule partitioning occurs by a biased increase in their condensation at the posterior end of the embryo. P granules were found to have a surprisingly liquid-like character, exhibiting behaviors such as fusion, dripping and wetting; their partitioning appears to represent a kind of liquid-liquid phase transition, in which polarity proteins establish a gradient in the condensation point across the cell. This gradient itself results from a spatially varying diffusivity of key polarity proteins. P granule partitioning thus reflects an intracellular phase transition spatially regulated by a patterning reaction-diffusion process.