THEORETICAL PHYSICS

Field-theoretic renormalization group methods in stochastic dynamics: Study of non-equilibrium processes with fluctuating number of particles.

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consultant: RNDr. Tomáš Lučivjanský, PhD.
study form: full time

Annotation: In recent years there was a steady interest in interdisciplinary research field devoted to the class of reaction-diffusion models. Such models serve for the description of various phenomena such as proliferation of defects in material, infection spreading in biological system, and even spreading of political opinions. Apart from these models we will consider related problems of active matter physics, which represents a non-trivial application of phase transitions models on biological systems. Main focus of the work will be on study of specific chemical reaction schemes and percolation processes. Dynamic processes with non-conserved number of interacting entities can be formulated microscopically via master equation approach for probability distributions. This can be then recast into equations for state vectors employing Doi formalism. The ensuing models are tantamount to certain field-theoretic actions. The common property of such models is a presence of strong fluctuations in scaling regions, which effectively make ordinary perturbation theory useless. Methods that goes beyond mean-field like theories are needed. The aim of this work is therefore to employ perturbation methods of quantum field theory, functional integration and renormalization group. From the experimental and practical point of view the situation is similar to that in phase transitions. Very important role is played by critical indices that control behavior of statistical correlations of interacting agents. Higher order calculations provide obvious possibility to extent existing research status. In this work thus main practical method will be field-theoretic renormalization group.

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Stochastic dynamics and turbulence: Calculation of relevant parameters and anomalous exponents in higher orders of perturbation theory.

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study form: full time

Annotation: PhD thesis will be devoted to a theoretical analysis of complex classical systems using sophisticated methods of quantum field theory. Classical systems in consideration are formulated in a form of stochastic models, which describe a whole class of phenomena. Most relevant models are reaction-diffusion problems, equilibrium and non-equilibrium phase transitions, turbulent flows and others. A common feature of such systems is presence of strong fluctuation effects, which precludes use of the ordinary perturbation theory. It is necessary to go beyond and apply non-trivial perturbation methods of quantum field theory, functional integrals and renormalization group. From the experimental point of view we are interested in master observable parameters (Prandtl number, skewness and flatness factors, Kolmogorov constant etc.) and critical indices, because they determine behavior of statistical correlations of random fields on large spatial scales. The research in this area has achieved a point in which parameters and critical indices are known in the leading order. Calculations of such quantities in higher orders of perturbation theory (two- and three-loop) belong to a current task in modern theoretical physics. Concrete calculations of multi-loop Feynman diagrams are very demanding and challenging problems. They require the development of new numerical and symbolic algorithms, which can be implemented on computers. Besides an adequate knowledge of modern physics it is expected that a candidate is well acquainted with programming languages and techniques.

Skyrmion phases in geometrically frustrated spin systems.
supervisor: doc. RNDr. Milan Žukovič, PhD. (milan.zukovic@upjs.sk)
study form: full time
Annotation: An antisymmetric Dzyaloshinskii-Moriya spin exchange interaction (DMI) can lead to the formation of twisted magnetic structures. These have attracted much interest mainly after the experimental observation of nontrivial magnetic configurations, called magnetic skyrmion lattices, which have potential technological applications. In ferromagnetic (FM) systems, the skyrmion phase arises from the competition between FM interactions and DMI and it is stabilized by a magnetic field and thermal fluctuations. A similar antiferromagnetic (AFM) skyrmion phase has been discovered in the frustrated classical AFM triangular-lattice Heisenberg model in the field not only with DMI but also without DMI due to further neighbor exchange interactions. It has been shown that magnetic frustration can improve stability of the skyrmion phase and that the usage of AFMs in skyrmion-based devices has certain advantages over the implementation of FM magnets. The goal of the proposed research is theoretical search for suitable candidates among geometrically frustrated AFMs that would display skyrmion phases with physically and technologically interesting properties.

Prediction of space-time data using models from statistical physics.
supervisor: doc. RNDr. Milan Žukovič, PhD. (milan.zukovic@upjs.sk)
study form: full time
Annotation: The ever increasing amount of space-time data, e.g. from Earth observation through various remote sensing techniques, requires the development of new, efficient (often real-time) and automated processing methods that also include the prediction of missing data. Traditional prediction methods are not suitable for such massive data, particularly due to high computational complexity as well as other limitations. The proposed research aims to develop strategies for efficient prediction methods inspired from statistical physics models that would be flexible and suitable for automated processing using massively parallel algorithms implemented on graphics processor units (GPU).

Localized magnons as a tool for investigation of frustrated Heisenberg and Hubbard models.
supervisor: doc. RNDr. Jozef Strečka, PhD. (jozef.strecka@upjs.sk)
study form: full time

Annotation: Geometric spin frustration of quantum Heisenberg and Hubbard models may under certain circumstances lead to existence of unusual bound quantum states known as localized magnons. The dissertation thesis will be devoted to a theoretical study of selected frustrated quantum Heisenberg and Hubbard models, whose low-temperature behavior can be described within the classical lattice-gas models on account of bound states with character of localized magnons.

References:

1. O. Derzhko, J. Richter, Universal low-temperature behavior of frustrated quantum antiferromagnets in the vicinity of the saturation field, European Physical Journal B 52 (2006) 23–36.
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Theoretical investigation of phase separation in binary and ternary liquid mixtures.

supervisor: doc. RNDr. Jozef Strečka, PhD. (jozef.strecka@upjs.sk)
study form: full time

Annotation: The phase separation of binary and ternary liquid mixtures will be investigated within the framework of the lattice-statistical models such as the generalized Frenkel-Louis and Lin-Taylor models. In particular, the main emphasis will be laid by accounting for the multiparticle (e.g. three-body) interactions, which may play a crucial role in determining possible non-universal critical behavior. Besides, the dissertation thesis will focus on a problem of reentrant miscibility of some binary and ternary liquid mixtures with highly orientation-dependent forces (e.g. hydrogen bonding).

References:

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Magnetoelectric effect in layered magnetic systems from first principles.

supervisor: RNDr. Martin Gmitra, PhD. (martin.gmitra@upjs.sk)
study form: full time

Annotation: Novel quantum states in condensed matter physics and material science attract nowadays a great attention. Ferroelectric materials intrinsically break time-reversal symmetry, a key symmetry for topological states in topological insulators, opening thus a route towards magnetic and electric control of topological nontrivial states. The manipulation of magnetic properties by an electric field in magnetoelectric materials has remarkable technological potential [1]. Recently layered compound $MnBi_2Te_4$ has been predicted to realize the quantized topological magnetoelectric effect and axion electrodynamics in condensed matter systems [2]. The effect can be achieved by an unusual magnetic profile — that is, the magnetizations of the top and bottom surfaces of the system align oppositely [3]. By means of density functional theory (DFT) implemented in numerical methods of electronic structure calculations (also called calculations form first principles or ab-initio methods) [4,5] we can study various properties of discovered and search for novel materials with quantized topological magnetoelectric effect.

References:

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Study of universal properties of turbulent systems using quantum field theory methods.
supervisor: RNDr. Marián Jurčišin, PhD. (jurcisin@saske.sk), Institute of Experimental Physics Slovak Academy of Sciences Košice
study form: full time
Annotation: Using quantum field theory methods, the influence of various symmetry breakings in turbulent environments on the universal properties of diffusion processes in such systems as well as on the anomalous scaling of correlation functions of passive scalar (e.g., the temperature field in the atmosphere) and vector (e.g., the magnetic field in conductive turbulent environments) admixture fields will be studied.