Exploring New Topics with Functional Renormalisation

French-German
WE-Heraeus-Seminar

01 - 05 May 2023

at the Physikzentrum Bad Honnef
Germany

WILHELM UND ELSE
HERAEUS-STIFTUNG

Introduction

The Wilhelm und Else Heraeus-Stiftung is a private foundation that supports research and education in science with an emphasis on physics. It is recognized as Germany's most important private institution funding physics. Some of the activities of the foundation are carried out in close cooperation with the German Physical Society (Deutsche Physikalische Gesellschaft). For detailed information see https://www.we-heraeus-stiftung.de

Aims and Scope of the French-German WE-Heraeus-Seminar:

The aim of this workshop is to explore new avenues where functional renormalisation starts being used and offers high prospects. Possible subjects are:

- Non-equilibrium time evolution from cosmology to turbulence and ultracold atoms
- Active matter and biophysics
- Functional renormalisation for neural networks, artificial intelligence, cellular automata and economy
- Combination of functional renormalisation with other methods and numerical developments

These apparently very different fields are bridged by the development of common methods. We intend to bring together active groups working in France and Germany, together with a few speakers from other countries. We envisage to supplement topical talks by more school like elements where certain fields can be deepened for participants not working on the particular subject.

Scientific Organizers:

Prof. Dr. Bertrand Delamotte	Sorbonne University, E-mail: delamotte@lptmc.jussieu.fr
Prof. Dr. Nicolas Dupuis	Sorbonne University E-mail: nicolas.dupuis@sorbonne-universite.fr
Prof. Dr. Stefan Floerchinger	University of Jena E-mail: stefan.floerchinger@uni-jena.de
Prof. Dr. Christof Wetterich	University of Heidelberg E-mail: c.wetterich@thphys.uni-heidelberg.de

Introduction

Administrative Organization:

Dr. Stefan Jorda
Mojca Peklaj

Wilhelm und Else Heraeus-Stiftung
Kurt-Blaum-Platz 1
63450 Hanau, Germany

Phone +49 6181 92325-11
Fax +49 6181 92325-15
E-mail peklaj@we-heraeus-stiftung.de
Internet: www.we-heraeus-stiftung.de

Venue :

Physikzentrum
Hauptstraße 5
53604 Bad Honnef, Germany

Conference Phone +49 2224 9010-120

Phone +49 2224 9010-113 or -114 or -117
Fax +49 2224 9010-130
E-mail gomer@pbh.de
Internet: www.pbh.de

Taxi Phone +49 2224 2222

Registration:

Mojca Peklaj (WE Heraeus Foundation)
at the Physikzentrum, Reception Office
Sunday (17:00 h - 21:00 hrs) and Monday morning

Program

Program *(CEST)*

Sunday, 30 April 2023

17:00 – 21:00	ARRIVAL and REGISTRATION	
18:30	*BUFFET SUPPER*	

Monday, 01 May 2023

08:00	*BREAKFAST*	
Method Developments		
09:00 – 10:00	Bertrand Delamotte	**Introduction to Out of Equilibrium FRG**
10:00 – 10:45	Jan M Pawlowski	**Complex Flows for Complex Problems**
10:45 – 11:30	*COFFEE BREAK*	
11:30 – 12:00	**Discussion**	
12:00 – 12:45	Nicolás Wschebor	**The Use of Conformal Invariance in the Non-Perturbative Renormalisation Group Framework**
12:45 – 13:00	**Conference Photo (outside at the main entrance)**	
13:00 – 14:45	*LUNCH BREAK*	
14:45 – 15:30	Eduardo Grossi	**Dissipation Rate in Local Potential Approximation**
15 :30 – 16 :00	*COFFEE BREAK*	
16:00 – 16:45	Nicolas Wink	**Computational Fluid Dynamics and the fRG**
16:45 – 17:30	**Discussion**	

Program *(CEST)*

17:30 – 17:50	Andrey Katanin	**Local 2PI Vertex Approximation in 1PI Functional Renormalization Group Approach: From Graphene Nanoflakes to 3D Magnets**
17:50 – 18:10	Laura Batini	**Dissipation Rate in Local Potential Approximation**
18:10 – 18:30	Friederike Ihssen	**Optimal RG-flows and Flowing Fields**
18:30 – 18:50	Tim Stötzel	**Real Scalar Field Shear Viscosity using the Functional Renormalization Group**
19:00	*DINNER*	

Program *(CEST)*

Tuesday, 02 May 2023

08:00	*BREAKFAST*	
Active Matter and Biophysics		
09:00 – 10:00	Hugues Chaté	**Active matter: still an exciting and largely virgin playground for RG approaches**
10:00 – 10:45	Adam Kline	**Multi-relevance: Coexisting but Distinct Notions of Scale**
10:45 – 11:30	*COFFEE BREAK*	
11:30 – 12:00	**Discussion**	
12:00 – 12:45	Matthieu Tissier	**Phase Transitions in Active Matter**
12:45 – 14:45	*LUNCH BREAK*	
Information Theory and Measurement		
14:45 – 15:30	Sebastian Diehl	**Measurement Induced Phase Transitions: From Theory to Observability**
15 :30 – 16 :00	*COFFEE BREAK*	
16:00 – 16:45	Stefan Floerchinger	**Functional Renormalization and Information Geometry**
16:45 – 17:15	**Discussion**	
17:15 – 17:35	Patrick Jentsch	**Exact Scaling Exponents in Active Matter: Do they exist?**
17:35 – 17:55	Gregory Johnson	**Universality of the Yang Lee Edge Singularity from FRG**
17:55 – 18:15	Romain Daviet / Carl Philipp Zelle	**Universality at Critical Exceptional Points of Nonequilibrium O(N) Models**
18:15 – 18:45	**Flash Talks 1**	
18:45 – 19:00	Stefan Jorda	**About the Wilhelm und Else Heraeus Foundation**
19:00	*DINNER*	

Program *(CEST)*

Wednesday, 03 May 2023

08:00	*BREAKFAST*	
Neural Networks, Deep Learning, Cellular Automata		
09:00 – 09:45	Braden Brinkman	**Non-perturbative Renormalization Group Analysis of Spiking Neuron Networks**
09:45 – 10:30	Adam Rançon	**Inference and the Inverse Problem from a Field Theory and Renormalisation Group Perspective**
10:30 – 11:00	*COFFEE BREAK*	
11:00 – 11:45	Christof Wetterich	**Probabilistic Cellular Automata for Fermionic Quantum Field Theories**
11:45 – 12:25	**Discussion**	
12:25 – 12:45	Ari Pakman	**Non-perturbative Renormalization Group in Finite Dimensions**
12:45 – 14:45	*LUNCH BREAK*	
15:30 – 16:00	*COFFEE BREAK*	
Method Development		
16:00 – 16:45	Holger Gies	**Relativistic Luttinger Fermions and their Renormalization Flow**
16:45 – 17:30	Gilles Tarjus	**Spontaneous versus Explicit Replica Symmetry Breaking in the Theory of Disordered Systems**
17:30 – 17:50	Andrey Fedorenko	**Non-Anderson Disorder-driven Quantum Transition in Nodal Semimetals**
17:50 – 18:10	Markus B. Fröb	**Constructing CFTs from AdS Flows**
18:10 – 19:00	Bertrand Delamotte	**Introduction to Out of Equilibrium FRG**
19:00	*HERAEUS DINNER at the Physikzentrum (cold & warm buffet, with complimentary drinks)*	

Program *(CET)*

Thursday, 04 May 2023

08:00	*BREAKFAST*	

Non-equilibrium Time Evolution

09:00 – 09:45	Jürgen Berges	**Stability Properties of Nonthermal Fixed Points from Functional Methods**
09:45 – 10:30	Léonie Canet	**The Unpredicted Scaling of the One-dimensional Kardar-Parisi-Zhang Equation**
10:30 – 11:15	*COFFEE BREAK*	
11:15 – 11:45	**Discussion**	
11:45 – 12:05	Viktoria Noel	**Far from Equilibrium Universality and Non-thermal Fixed Points with fRG**
12:05 – 12:25	Aleksandr Mikheev	**A Functional Renormalization Group Approach to Non-thermal Fixed Points in an Ultracold Bose Gas**
12:25 – 12:45	Côme Fontaine	**Functional Renormalisation Group Approach to Shell Models of Turbulence**
12:45 – 14:45	*LUNCH BREAK*	

Method Development

14:45 – 15:45	Alessandro Toschi	**Merging Dynamical Mean-field Theory and Functional Renormalization Group for Correlated Electrons: A Stepping-stone for Mastering the Nonperturbative Regime in Two Dimensions**
15:45 – 16:15	*COFFEE BREAK*	
16:15 – 17:00	Walter Metzner	**Antiferromagnetism and d-Wave Pairing in the Strongly Interacting Two-dimensional Hubbard Model from the Functional Renormalization Group**

Program *(CET)*

17:00 – 18:30	**Flash Talks 2**
18:30	*DINNER*
19:30	**Poster Session**

Program *(CET)*

Friday, 05 May 2023

08:00	*BREAKFAST*	
Cosmology		
09:00 – 09:45	Nikolaos Tetradis	**Effective Theory of Large Scale Structure**
09:45 – 10:30	Urs Wiedemann	**RG-flow of the Effective Action of Cosmological Large-scale Structures**
10:30 – 11:15	*COFFEE BREAK*	
11:15 – 12:00	**Discussion**	
Method Development		
12:00 – 12:45	Nicolas Dupuis	**Flowing Bosonization in the Nonperturbative Functional Renormalization-group Approach**
12:45	*LUNCH*	

End of Seminar / Departure

Posters

Poster Session: Thursday, 04 May, 19:30 h (CEST)

1	Aiman Al-Eryani	**An fRG Analysis of the Extended Hubbard Model on the Square and Triangular Lattices**
2	Gabriel Assant	**Quantum Einstein Cubic Gravity**
3	Ivan Balog	**Renormalization Group and Probability Theory**
4	Alexander Baum	**Functional Renormalization of the Spin-1 Bose Gas**
5	Konstantinos Boutivas	**Entanglement and Expansion**
6	Luis Cancino Arancibia	**Renormalization Flow Analysis for Two Pomeron**
7	Louise Delzescaux	**The Flat Phase of Polymerized Membranes and Polymerized Membrane Bilayers**
8	Timon Dörnfeld	**Symmetry Breaking in Dense QCD Matter**
9	Tilman Enss	**Quantum Transport of Strongly Correlated Fermions**
10	Juergen Eser	**Linear and Nonlinear Realizations of Chiral Symmetry**
11	Lucija Nora Farkaš (presented by Ivan Balog)	**Lower Critical Dimension in the ϕ^4 Theory**
12	Gergely Fejős	**Fate of the Axial Anomaly at Finite Temperature**
13	Kilian Fraboulet	**Multiloop Single-boson-exchange fRG and its Application to the Two-dimensional Hubbard Model**

Poster Session: Thursday, 04 May, 19:30 h (CEST)

14	Andreas Geissel	**Speed of Sound of Strong-interaction Matter at Supranuclear Densities**
15	Nicolas Hendricks	**Investigating the Quark-Meson-Vector Meson Model with Functional Renormalisation Group Techniques**
16	Marcel Horstmann	**On the QCD Diffusion Coefficient**
17	Adrian Koenigstein	**Numerical Fluid Dynamics for FRG Flow Equations**
18	Akitoshi Okutsu	**Holographic Nonlinear Finance and its Connections to the Microeconomic Behavioral Structures**
19	Álvaro Pastor Gutiérrez	**Investigating Strong New Physics with Functional Methods**
20	Miriam Patricolo	**Pseudogap Opening in the Hubbard Model at Strong Coupling**
21	Marta Picciau	**3+1-dimensional Gauge Theories with Luttinger Fermions**
22	Janik Potten	**Frequency-resolved Functional Renormalization Group for Quantum Magnetic Systems**
23	Manuel Reichert	**Higher-derivative Quantum Gravity in the Fluctuation Approach**
24	Félix Rose	**FRG Approach to Equilibrium Transport beyond LPA'**
25	Carlos Sánchez	**Magnetic Systems with Discrete Anisotropies**

Poster Session: Thursday, 04 May, 19:30 h (CEST)

26	Franz Richard Sattler	**Numerical RG-time Integration of the Effective Potential: Analysis and Benchmark**
27	George Savvidy	**Renormalisation Group Equation for Yang-Mills Effective Lagrangian and Cosmological Inflation**
28	Jonas Stoll	**Towards the Equation of State of Color-superconducting Strong-interaction Matter**
29	Arthur Ferreira Vieira	**The Fate of Chiral Symmetry in Riemann-Cartan Spaces**
30	Jonas Wessely	**Scalar Spectral Functions from the Functional Renormalisation Group**
31	Shunsuke Yabunaka	**A Fixed Point Can Hide Another One: The Nonperturbative Behavior of the Tetracritical Fixed Point of the O(N) Models at Large N**
32	Niklas Zorbach	**From Fluid Dynamics to RG Flow Studies of Phase Transitions**

Abstracts of Lectures

(in alphabetical order)

Dissipation rate in local potential approximation

<u>L. Batini</u>[1] E. Grossi[2] and N. Wink[3]

[1]Institut für Theoretische Physik, Universität Heidelberg, Philosophenweg 16, 69120 Heidelberg, Germany

[2] Institut für Kernphysik, Technische Universität Darmstadt, Schlossgartenstrasse 2, 64289 Darmstadt, Germany

[2] Dipartimento di Fisica, Università di Firenze and INFN Sezione di Firenze, via G.Sansone 1, 50019 Sesto Fiorentino, Italy

In this work, we study non-equilibrium critical phenomena by employing the framework of the non-perturbative functional renormalization group (FRG). As low-energy effective theory model in the classical-statistical limit, we use Model A, which consists of a scalar field theory with relaxational dynamics.

Using the local potential approximation (LPA) of the derivative expansion for the truncation of the effective action, we numerically solve the coupled flow equations for the relaxation rate and the effective potential. This approach allows us to study the critical regime and compute the static critical exponents of the model. Furthermore, using a finite size scaling analysis, we extract the dynamic critical scaling exponent z, that agrees with the existing value from the literature. The relaxation rate in this model has a physical relevance when interpreting effective potentials as input in dynamic simulations.

References

1. U. C. Tauber, Critical Dynamics: A Field Theory Approach to Equilibrium and Non-Equilibrium Scaling Behavior, (Cambridge University Press, 2014).
2. L. Canet, H. Chate, and B. Delamotte, General framework of the non-perturbative renormalization group for non-equilibrium steady states, J. Phys. A 44, 495001 (2011).

Non-perturbative renormalization group analysis of spiking neuron networks

Braden A. W. Brinkman[1]

[1] *Department of Neurobiology and Behavior, Stony Brook University, Stony Brook, New York, USA*

The critical brain hypothesis posits that neural circuits may operate close to critical points of a phase transition, which has been argued to have functional benefits for neural computation. However, neural activity is composed of all-or-nothing pulses called “spikes,” and this activity is nonlinear, non-local, and non-Gaussian, rendering models that capture all of these features difficult to study using standard statistical physics techniques. Theoretical and computational studies arguing for or against criticality in neural dynamics have largely relied on establishing power laws or scaling functions in simulations or mean-field models; a renormalization group analysis of criticality in spiking networks of neurons has been lacking. Here, I report on recent work [1] that overcomes these issues by adapting the non-perturbative renormalization group (NPRG) to work on (symmetric) network models of stochastic spiking neurons. Using a local potential approximation, I show the method enables calculation of non-universal quantities such as the effective firing rate nonlinearity of the network, as well as fixed points of the dimensionless flow equations. The spiking network admits at least two important types of critical points: in networks with an absorbing state there is Directed Percolation (DP) fixed point corresponding to a non-equilibrium phase transition between sustained activity and extinction of activity, and in spontaneously active networks there is a complex valued, but physically meaningful, critical point, corresponding to a first order phase transition with universal scaling behavior.

References

[1] B. A. W. Brinkman, arxiv:2301.09600 (2023)

The unpredicted scaling of the one-dimensional Kardar-Parisi-Zhang equation

F. Vercesi[1], C. Fontaine[1], M. Brachet[2], and Léonie CANET[1,3]

[1] Laboratoire de Physique et Modélisation des Milieux Condensés, Université Grenoble Alpes and CNRS, Grenoble, France
[2] Laboratoire de Physique de l'ENS, Université PSL and Sorbonne Université, Paris, France
[3] Institut Universitaire de France, Paris, France

The celebrated Kardar-Parisi-Zhang (KPZ) equation describes the kinetic roughening of stochastically growing interfaces. In one dimension, the KPZ equation is exactly solvable, and its statistical properties are known to an exquisite degree. Yet recent numerical simulations [1] unveiled a new scaling, with a dynamical exponent $z=1$ different from the KPZ one $z=3/2$. In this talk, I will show that this scaling is controlled by a fixed point which has been missed so far and which corresponds to an infinite effective coupling. This fixed point can be accessed using the functional renormalisation group, and it yields $z=1$. The FRG also allows for the calculation of the correlation function at this fixed point. I will discuss the associated scaling function, providing both an analytical asymptotic form and the complete numerical solution, which accurately match the result from the numerical simulations.

References

[1] C. Cartes, E. Tirapegui, R. Pandit, M. Brachet, Phil. Trans. Roy. Soc. A **380**, 20210090 (2022)
[2] F. Vercesi, C. Fontaine, M. Brachet, L. Canet, *to be submitted* (2023)

Active matter: still an exciting and largely virgin playground for renormalization group approaches

Hugues Chaté

CEA – Saclay, France & Beijing Computational Science Research Center, China

Active matter incorporates constituents that transform energy, stored internally or gathered from their environment, into mechanical work. I will first describe a few spectacular real-life examples of such systems, and then try to draw, from my personal perspective, a panorama of this still fast-growing multi-form field. I will then focus on two core problems that are best understood today, drawing mostly from my own work:

- long-range orientational order emerging from the breaking of a continuous symmetry in 2D active systems
- phase separation in collections of active particles interacting via pairwise repulsion

I will provide an update, present some important recent results, and discuss existing RG approaches. Given that these are almost all at the level of simple 'dynamical RG' one-loop calculations, my conclusion is simple: functional, non-perturbative RG skills are much needed!

Exceptional critical point in non-equilibrium O(N)

C. Zelle[1], R. Daviet[1], A.Rosch[1], S. Diehl[1]

[1] *Institut für theoretische Physik, Universität zu Köln, Germany*

Exceptional points are a hallmark of systems governed by non-Hermitian generators of dynamics, where reversible and irreversible dynamics compete. At these points, modes coalesce and degeneracies in the spectrum arise. We study the universal many-body physics that emerges when an exceptional point coincides with a critical point.

To this end, we use the O(N) model suitably driven out of equilibrium by tuning the damping to zero and negative values. This model hosts a non-equilibrium phase with a limit cycle traced out by the order parameter on the N-dimensional sphere. Within the limit cycle phase, we find an enhanced number of $2N - 3$ Goldstone modes, due to the breaking of O(N) down to O(N-2), and elucidate their nature and basic excitation properties.

The transition from the statically ordered phase into the dynamically ordered phase, occurs via a critical exceptional point characterized by the presence of coherence and dissipation in the dispersion and an enhanced 1/q^4 divergences of the two-point correlation function above the upper critical dimension d_c=4. Below four dimensions however, these fluctuations preclude the existence of a critical point and the phase transition is rendered first order in a mechanism with formal similarities to Brazovskii's scenario as we show for N=2. The non-analyticities induced by the exceptional point preclude a naive gradient expansion. On the other hand, they result in a decoupling of the hierarchy of Dyson-Schwinger equations, with closed equations for the self-energy and vertex function that can be solved. For generic N, we expect this scenario to hold and are currently implementing the FRG approach to study it.

Our model describes the critical behaviour of non-reciprocal phase-transition found in [1,2]. We also propose a new microscopic realization in driven Heisenberg magnets in solid state.

References

[1] Fruchart, Hanai, Littlewood, Vitelli, Nature 592, 363-369 (2021)

[2] Hanai, Littlewood, Phys. Rev. Research 2, 033018

Introduction to out of equilibrium FRG

B. Delamotte
Sorbonne University, Paris, France

Bertrand DELAMOTTE, Sorbonne Université, CNRS, Laboratoire de Physique Théorique de la Matière Condensée, LPTMC, F-75005 Paris, France

An introduction to out of equilibrium statistical mechanics will be given with emphasis on problems that can only be solved with the functional non perturbative renormalization group. The presentation will be mainly pedagogical.

Deep Learning the Functional Renormalization Group Flow for Correlated Fermions

D. Di Sante[1,2], M. Medvidović[2,3], A. Toschi[4], G. Sangiovanni[5], C. Franchini[1,6], A. M. Sengupta[2,7,8] and A. J. Millis[2,3]

[1]Department of Physics and Astronomy, University of Bologna, Italy
[2]Center for Computational Quantum Physics, Flatiron Institute, New York
[3]Department of Physics, Columbia University, New York, USA
[4]Institute of Solid State Physics, TU Wien, Vienna, Austria
[5]Institut für Theoretische Physik und Astrophysik, Würzburg, Germany [6]University of Vienna, Faculty of Physics and Center for Computational Materials Science, Vienna, Austria
[7]Center for Computational Mathematics, Flatiron Institute, New York [8]Department of Physics and Astronomy, Rutgers University, New Jersey

I will present a data-driven dimensionality reduction of the scale-dependent 4-point vertex function characterising the functional Renormalization Group (fRG) flow for the widely studied two-dimensional $t - t'$ Hubbard model on the square lattice. It will be shown that a deep learning architecture based on a Neural Ordinary Differential Equation solver in a low-dimensional latent space efficiently learns the fRG dynamics that delineates the various magnetic and d-wave superconducting regimes of the Hubbard model. In addition, a Dynamic Mode Decomposition analysis confirms that a small number of modes are indeed sufficient to capture the fRG dynamics.
This talk will demonstrate the possibility of using artificial intelligence to extract compact representations of the 4-point vertex functions for correlated electrons, a goal of utmost importance for the success of cutting-edge quantum field theoretical methods for tackling the many-electron problem.
Besides the specific application to correlated fermions, I will discuss a dimensionality reduction scheme that may be useful to any research field dealing with presumable very high-dimensional data.

References

D. Di Sante et al, Phys. Rev. Lett. **129**, 136402 (2022)

Measurement Induced Phase Transitions: From Theory to Observability

S. Diehl[1]

[1]*Institute for Theoretical Physics, University of Cologne*

The quest for phases and phase transitions in general non-unitary quantum dynamics has been spotlighted by the recent discovery of measurement-induced phase transitions. They result from the competition of deterministic Schrödinger and random measurement dynamics, and surface in a qualitative change of the entanglement structure.
Here we first introduce instances of entanglement transitions in fermion systems, between a regime of logarithmic entanglement growth, and a quantum Zeno regime obeying an area law. We identify the relevant degrees of freedom driving the phase transition in terms of an effective field theory. This yields a physical picture in terms of a depinning from the measurement operator eigenstates induced by unitary dynamics, and places it into the BKT universality class.
In standard quantum mechanical observables however, these transitions are masked due to the degeneracy of measurement outcomes. We then point out a general route of gently breaking this degeneracy -- pre-selection -- which makes such transitions observable in state-of-the-art quantum platforms without modifying any of the universal properties. It reveals an intriguing connection to quantum absorbing state transitions.

References

[1] O. Alberton, M. Buchhold, S. Diehl, *Entanglement Transition in a Monitored Free-Fermion Chain: From Extended Criticality to Area Law* , Phys. Rev. Lett. 126, 170602 (2021) , arxiv:2005.09722

[2] M. Buchhold, Y. Minoguchi, A. Altland, S. Diehl, *Effective Theory for the Measurement-Induced Phase Transition of Dirac Fermions* , Phys. Rev. X 11, 041004 (2021) , arxiv:2102.08381

[3] M. Buchhold, T. Müller, S. Diehl, *Revealing measurement-induced phase transitions by pre-selection* , arxiv:2208.10506

Flowing bosonization in the nonperturbative functional renormalization-group approach

Nicolas Dupuis

Laboratoire de Physique Théorique de la Matière Condensée,
Sorbonne Université & CNRS, Paris, France

Bosonization allows one to describe the low-energy physics of one-dimensional quantum fluids within a bosonic effective field theory formulated in terms of two fields : the "density" field φ and its conjugate partner, the phase θ of the superfluid order parameter. We discuss the implementation of the nonperturbative functional renormalization group in this formalism, considering a Luttinger liquid in a periodic potential as an example. We show that in order for θ and φ to remain conjugate variables at all energy scales, one must dynamically redefine the field θ along the renormalization-group flow. Only with this scale-dependent (flowing) reparametrization of the phase field θ do we obtain the standard phenomenology of the Luttinger liquid (when the periodic potential is sufficiently weak so as to avoid the Mott-insulating phase) characterized by two low-energy parameters, the velocity of the sound mode and the renormalized Luttinger parameter.

References :

[1] R. Daviet and N. Dupuis, *Flowing bosonization in the nonperturbative functional renormalization-group approach*, SciPost Phys., 2022, **12**, 110.

Non-Anderson disorder-driven quantum transition in nodal semimetals

I. Balog[1], E. Brillaux[2], D. Carpentier[2], A. Fedorenko[2], I. Gruzberg[3]

[1] *Institute of Physics, Zagreb, Croatia*
[2] *CNRS, Laboratoire de Physique, ENS de Lyon, France*
[3] *Ohio State University, Columbus, USA*

The recent discovery of materials, such as Weyl and Dirac semimetals, whose low-energy properties are described by three-dimensional relativistic fermions opened fascinating opportunities to study physical phenomena which have never been accessible before. Among these phenomena is a remarkable disorder driven quantum transition from the semimetal towards a diffusive metallic phase characterized by a finite density of states at the band crossing. This transition is different from the Anderson localization transition but exhibits many similar properties such as multifractality of critical wave functions and broad distribution of density of states. The existence of surface states such as Fermi arcs also leads to new rich surface critical phenomena. I will review recent progress in understanding different aspects of this transition including multifractality and surface criticality. I also show how the functional renormalization group can be useful for studying this disordered quantum system.

References

[1] I. Balog, D. Carpentier, A. A. Fedorenko, Phys. Rev. Lett. **121**, 166402 (2018)
[2] E. Brillaux, D. Carpentier, A.A. Fedorenko, Phys. Rev. B **100**, 134204 (2019)
[3] E. Brillaux and A. A. Fedorenko, Phys. Rev. B **103**, L081405 (2021)
[4] E. Brillaux, A. A. Fedorenko, I.A. Gruzberg (in preparation)

Functional renormalization and information geometry

Stefan Floerchinger

Theoretisch-Physikalisches Institut, Friedrich-Schiller Universität Jena, Germany

E-mail: stefan.floerchinger@uni-jena.de

Abstract: Bosonic quantum field theories in Euclidean spaces have a probabilistic interpretation. With the functional renormalization group one can calculate expectation values, correlation function, phase diagrams, thermodynamic potentials and so on, in a non-perturbative way. On the other side, information geometry provides a mathematical understanding for spaces of probabilty distributions using concepts like the Fisher information metric, divergences like the one of Kullback and Leibler, connections, non-metricity, the Amari-Chentsov dual structure and so on. I will discuss how these two formalisms are related and how conceptual understanding can be transfered between them.

Functional Renormalisation group approach to shell models of turbulence

<u>Côme Fontaine</u>[1], Malo Tarpin[2], Freddy Bouchet[2] and Léonie Canet[1]

[1]*Univ. Grenoble Alpes, CNRS, LPMMC, 38000 Grenoble, France*

[2]

The scaling properties of the velocity field of an homogeneous and isotropic turbulent flow are extensively studied numerically and experimentally, and are known to exhibit multi-fractality. While there exist some theoretical descriptions of this phenomenon based on phenomenological arguments, it is a notoriously difficult problem to calculate the multi-fractal exponents from the equations of motion themselves. In this respect, toy models of turbulence, such as shell models, play an important role to make progress in the understanding of the emergence of multi-fractality. Shell models are a family of reduced models of fluid mechanics, that are both analytically and numerically much simpler than the full Navier-Stokes equation, while exhibiting very similar properties. Among these models, the Sabra model in particular accurately reproduces the multi-fractal exponents observed in the Navier Stokes equation. In this work, we set up a functional renormalisation group formalism to study shell models of turbulence, and then focus on the Sabra shell model. We establish the existence of the fixed point describing the turbulent state within a simple approximation, and study its statistical properties.

Constructing CFTs from AdS flows

M. B. Fröb[1]

[1]*Institut für Theoretische Physik, Universität Leipzig,*
Brüderstr. 16, 04103 Leipzig, Germany

Employing the renormalisation group flow equations for weakly coupled quantum field theories in Anti-de Sitter space (AdS), I show how one can apply the AdS/CFT correspondence to obtain flow equations for the dual large-N conformal field theories (CFTs). In this duality, loop corrections in the AdS bulk are mapped to 1/N corrections in the CFT. I derive recursion relations for CFT correlation functions which generalize existing results in the large-N limit to all orders in the 1/N expansion, and show how these translate directly into recursion relations for the corresponding Mellin amplitudes.

References

[1] M. B. Fröb, JHEP **09**, 168 (2022)

Relativistic Luttinger fermions and their renormalization flow

Holger Gies

[1]FSU Jena, TPI & Abbe-Center of Photonics, Max-Wien-Platz 1, 07743 Jena
[2] Helmholtz Institute Jena & GSI Darmstadt

Luttinger fermions are well known in non-relativistic solid-state physics describing effective low-energy degrees of freedom near Fermi points when the dispersion is quadratic. We present the construction of the corresponding relativistic version of Luttinger fermions with the aid of a spin-base-invariant formulation of spinor field theories. The resulting fermion fields exhibit a canonical scaling different from Dirac fermions and thus support the construction of novel relativistic and perturbatively renormalizable interacting quantum field theories. In particular, new asymptotically free self-interacting field theories can be constructed. This paves the way for using the functional renormalization group to explore corresponding nonperturbative challenges such as fluctuation-induced phase transitions, properties of the long-range physics, and a possible transition of the Luttinger spin-base group to that of Dirac fermions.

Dissipation rate in local potential approximation

E.Grossi[1]

[1]*Univiersity of Florence & INFN*

To study critical non-equilibrium phenomena or close to equilibirum phenomena, Model A is one of the simplest models. It consists of a scalar field theory that fluctuates. Model A exhibits a divergence in its relaxation time or dissipation rate near the second-order phase transition temperature Tc which is characterized by the dynamical exponent z and the d. We numerically solve the coupled flow equations for the relaxation rate and the effective potential. We use the LPA approximation of derivative expansion to second order for the truncation of the effective action in a stationary case's classical-statistical (high temperature) limit. Using a finite-size scaling analysis we extract the dynamic scaling critical exponent z, which agrees with the existing value from the literature

Optimal RG-flows and flowing fields

Friederike Ihssen[1] **and Jan M. Pawlowski**[1, 2]

[1] *Institut für Theoretische Physik, Universität Heidelberg, Philosophenweg 16, 69120 Heidelberg, Germany*

[2] *ExtreMe Matter Institute EMMI, GSI, Planckstr. 1, 64291 Darmstadt, Germany*

In my talk I present a fRG approach in which we use general scale-dependent RG transformations for qualitative and quantitative improvements in the computation of the (1PI) effective action [1]. The formulation of the general RG flow is based on [2].
Using such RG transformations, we can set up a system of adaptive RG flows that corresponds to an optimal systematic expansion of the theory about the ground state or rather its full covariance/propagator. In this approach, the parametrisations are induced by flowing fields that encode the successive reparametrisation steps. This setup is used for a O(N) theory in four dimensions for describing its thermal phase transition. In view of later applications to QCD, explicit results are provided for N=4. The results are compared with those obtained in a common and related approximation for the O(N) model which includes a full effective potential and a running wave function renormalisation (LPA').

References

[1] Friederike Ihssen and Jan M. Pawlowski, in Preparation
[2] Jan M. Pawlowski, Annals of Physics 322 12, 2831-2915 (2007)

Exact Scaling Exponents in Active Matter: Do they exist?

P. Jentsch[1] **and C. F. Lee[1]**

[1]*Department of Bioengineering, Imperial College London,*
South Kensington Campus, London SW7 2AZ, United Kingdom
Email: p.jentsch20@imperial.ac.uk and c.lee@imperial.ac.uk

Active matter studies the macroscopic properties of materials made up of actively, i.e., self-propelling, particles such as flocks of birds, cell tissues or bacterial swarms. These systems share many similarities with conventional condensed matter systems, but the intrinsic out-of-equilibrium nature unexpectedly modifies typical behavior.

Specifically, the spontaneous symmetry breaking in flocking systems produces Goldstone-like long-range correlations that, due to self-advection, acquire an anomalous dimension in the ordered phase. While for the general compressible case no analytic estimate exists for these exponents, the incompressible case was not only solved but the scaling exponents have been claimed to be exact between $4>d>2$ dimensions [1].

However, since the argument in Ref. [1] is constructed from a perturbative formulation of the renormalization group only, using the functional renormalization group, we explore how these exponents can remain exact, even in a nonperturbative setting.

References

[1] L. Chen, C. F. Lee, J. Toner, New Journal of Physics **20**, 113035 (2018)

Universality in the complex plane from FRG

Gregory Johnson[1]

[1]*North Carolina State University, Raleigh, NC, United States*

The Lee-Yang theory of phase transitions has long been a fundamental approach to the study of critical phenomena. A feature common to this approach is the Yang-Lee edge singularity associated with Ising-like theories. It is itself a distinct fixed point that exists in the complex plane of the parameters of the underlying theory. Furthermore, the location of the Yang-Lee edge singularity within the critical region for the classical O(N) universality classes augments the conventional universal data. This result was not computed for any physically relevant three dimensional universality classes until somewhat recently (Ref. [1]). In this talk I will review the recent work (Ref. [2]) on extending the results of our original study (Ref. [1]) using FRG to compute the universal location of the Yang-Lee edge singularity. We developed a new method for computing the location and extended the precision of the results within the derivative expansion from LPA' to a truncated next-to-leading order scheme utilizing the principle of minimal sensitivity.

References

[1] A. Connelly, G. Johnson, F. Rennecke, V. Skokov, Phys Rev Lett **125**, 191602 (2020)

[2] G. Johnson, F. Rennecke, V. Skokov, arXiv:2211.00710

Local 2PI Vertex Approximation in 1PI Functional Renormalization Group Approach: From Graphene Nanoflakes to 3D Magnets

V. S. Protsenko[1], P. A. Igoshev[!], and A. A. Katanin[2]

[1] *Institute of Metal Physics, Ekaterinburg*

[2] *Moscow Institute of Physics and Technology, Dolgoprudny*

We consider applications of the local 2PI vertex approximation in 1PI functional renormalization group (fRG) approach, which was first introduced in the context of inhomogeneous Fermi systems [1] and later in the context of truncated unity (TU) approach [2]. We apply this approach to study charge- and spin instabilities in clean and disordered graphene nanoflakes, as well as in 3D itinerant magnets with higher order van Hove singularities. In clean graphene nanoflakes we find [3] semimetal phase for realistic Coulomb interaction but show that the phase boundary of charge density wave (CDW) instability strongly changes when the realistic interaction is replaced by the simplified screened long range Coulomb interaction. For the latter interaction, the boundaries of CDW and spin density wave (SDW) instabilities are in good agreement with Quantum Monte Carlo analysis. The obtained phase boundaries also agree with those obtained in the non-local extension of extended dynamical mean-field theory approach [4], which also assumes locality of 2PI vertex. In the presence of vacancies, we find [5] SDW order induced by vacancies.

Application of the local 2PI vertex TU fRG approach to 3D itinerant magnets with higher order van Hove singularities [6] shows ferromagnetic order near van Hove singularity with the first order quantum phase transitions to paramagnetic phase when the Fermi level is moved sufficiently far away from the van Hove singularity. In the considered cases we find no traces of incommensurate long range order.

In summary, the local 2PI vertex approximation in 1PI functional renormalization group approach is a convenient tool to study charge- and spin instabilities in correlated electronic systems (both, homogeneous and inhomogeneous) at relatively low computational cost and can be used in future studies.

References

[1] F. Bauer, J. Heyder, and J. von Delft, Phys. Rev. B **89**, 045128 (2014); L. Weidinger, F. Bauer, and J. von Delft, Phys. Rev. B **95**, 035122 (2017).

[2] C. J. Eckhardt, G. A. H. Schober, J. Ehrlich, C. Honerkamp, Phys. Rev. B **98**, 075143 (2018).

[3] V. S. Protsenko, A. A. Katanin, Phys. Rev. B **104**, 245139 (2021).

[4] A. A. Katanin, Phys. Rev. B **104**, 245142 (2021).

[5] V. S. Protsenko, A. A. Katanin, in preparation.

[6] P. A. Igoshev, A. A. Katanin, Phys. Rev. B **107**, 115105 (2023).

Multi-Relevance: Coexisting but Distinct Notions of Scale

A.G. Kline[1] and S.E. Palmer[2]

[1]Deptartment of Physics, University of Chicago, Chicago, Illinois 60637, USA
[2]Department of Organismal Biology and Anatomy and Department of Physics, University of Chicago, Chicago, Illinois 60637, USA

Recently, RG methods have seen use in problems in statistical physics, biology, and computer science, where models are distributions over high-dimensional spaces. In such domains, systems frequently have many collective states, necessitating analysis beyond linear coarse-graining. Tools from information theory can help define these non-linear coarse-graining maps, but their resulting flow equations are bound to be significantly more complicated [1]. In this work, we account for collective states by assigning each to a component of a mixture model. The resulting distribution can be thought of as having multiple coexisting, exactly independent RG flows, each with its own notion of scale. We define this property as multi-relevance. To explore some of its consequences on RG analysis, we construct a toy model that has two components, each corresponding to the state of an unobserved latent variable. In the regime where this latent variable can be inferred using a linear classifier, standard RG techniques can be applied successfully but will give different answers depending the choice of expansion point in state space. In the regime where linear estimation of the latent state fails, we show that an application of the vertex expansion predicts a decrease in the total number of relevant couplings from four to three. One consequence of this is that the application of PCA-like coarse-graining to a multi-relevant system can eliminate important, resolvable parameters, and further, it may only identify mixed collective degrees of freedom. Because multi-relevance can arise from the presence of distinct latent categorical states, it is a good starting point for the treatment of biological systems, where multiple notions of relevance from inputs in the external world are combined. Taken together, these results suggest that applications of RG in these new domains requires a proper accounting for multi-relevance.

References

[1] A.G. Kline S.E. Palmer, New J. Phys. **24**, 033007 (2022)

Antiferromagnetism and d-wave pairing in the strongly interacting two-dimensional Hubbard model from the functional renormalization group

W. Metzner

Max-Planck-Institut für Festkörperforschung, D-70569 Stuttgart, Germany

Using the dynamical mean-field theory (DMFT) as a "booster-rocket", the functional renormalization group (fRG) can be upgraded from a weak-coupling method to a powerful computation tool for strongly interacting fermion systems, the DMF^{2}RG [1]. The strong local correlations are treated non-perturbatively by the DMFT, while the fRG flow can be formulated such that it is driven exclusively by non-local correlations, which are more amenable to approximations. The full frequency dependence of the two-particle vertex needs to be taken into account in this approach, and we show that this is actually possible – in spite of the singular frequency dependence of the vertex at strong coupling. We present first results obtained from the DMFT-boosted fRG for the two-dimensional Hubbard model in the strongly interacting regime [2]. Strong antiferromagnetic correlations are dominant from half-filling to about 18 percent hole-doping, and, at the lowest temperature we can access, we find a sizable d-wave pairing interaction driven by magnetic correlations at the edge of the antiferromagnetic regime.
Finally, we discuss recent attempts to extend the DMF^{2}RG to symmetry-broken phases.

References

[1] C. Taranto et al., Phys. Rev. Lett. **112**, 196402 (2014).
[2] D. Vilardi, C. Taranto, and W. Metzner, Phys. Rev. B **99**, 104501 (2019).

A functional renormalization group approach to non-thermal fixed points in an ultracold Bose gas

A.N. Mikheev[1,2] , J.M. Pawlowski[2,3], and T. Gasenzer[1,2]

[1] *Kirchhoff-Institut für Physik, Ruprecht-Karls-Universität Heidelberg, Im Neuenheimer Feld 227, 69120 Heidelberg, Germany*
[2] *Institut für Theoretische Physik, Ruprecht-Karls-Universität Heidelberg, Philosophenweg 16, 69120 Heidelberg, Germany*
[3] *ExtreMe Matter Institute EMMI, GSI, Planckstraße 1, 64291 Darmstadt, Germany*

Classification and understanding of scaling solutions in closed quantum systems far from thermal equilibrium, known as non-thermal fixed points, is one of the open problems in non-equilibrium quantum many-body theory. The usual method involves searching for possible self-similar solutions to a (non-perturbative) evolution equation, e.g., Boltzmann or Kadanoff–Baym, starting from a far-from-equilibrium initial condition. We outline an alternative approach based on the correspondence between scaling and fixed points of the renormalization group. Using an ultracold Bose gas as an example we show how possible far-from-equilibrium scaling solutions can be systematically obtained by solving fixed-point renormalization-group equations.

Far from equilibrium universality and non-thermal fixed points with fRG

V. Noel[1], M. Tarpin[2], A. N. Mikheev[1,3] and J. Berges[1]

[1]*Institute for Theoretical Physics, Heidelberg, Germany*
[2]*École Centrale de Lyon, Lyon, France*
[3]*Kirchhoff-Institute for Physics, Heidelberg, Germany*

Nonthermal fixed points represent attractor solutions characterised by universal self-similar scaling behaviour in isolated many-body systems far from equilibrium. Such universal self-similar dynamics has been observed in cold atom experiments and numerical simulations, however a comprehensive renormalisation group formulation in terms of fixed points is lacking to date.

In this work, the universal scaling behaviour of O(N) symmetric scalar field theories is investigated far from equilibrium with the 1/N expansion at next-to-leading order, using the functional renormalisation group with the two-particle irreducible effective action formalism.

Non-perturbative Renormalization Group in Finite Dimensions

B. Brikman[1] and A. Pakman[2]

[1] *Stony Brook University, NY, USA*
[2] *Ben-Gurion University of the Negev, Beer Sheva, Israel*

The Legendre transform of the cumulant generating function of a probability distribution, called rate function in finite dimensions and effective potential in field theory, is a convex functional whose geometry encodes all the moments or correlation functions. In field theory it can be obtained non-perturbatively from the Wetterich equation, a functional differential equation that describes the gradual incorporation of fluctuations along the renormalization group flow. In this work we show that a similar flow equation naturally holds for finite-dimensional distributions. Moreover, while field theory solutions require truncations and approximations in the functional space, finite-dimensional solutions are only limited by the numerical precision of the integration of the Wetterich equation. This in turn allows to explore the effects of boundary conditions and regulators in an exact setting. We illustrate this technique to compute rate functions and its derivatives in several examples which exhibit excellent agreement with known exact results.

Complex flows for complex problems

Jan M. Pawlowski[1]

[1] Institut für Theoretische Physik, Universität Heidelberg, Philosophenweg 16, 69120 Heidelberg, Germany

The physics of many interesting and complex quantum systems can be accessed via their complex generating functionals. Relevant examples range from time-like scattering events and the dynamics in real-time QFTs, the computation of Lee-Yang zeros for restricting the phase structure of strongly correlated systems, QFTs at finite density or with spin imbalance to theories with emergent dynamics. While in the former examples the generating functionals are complex, in the last example the dynamics is complex. In most of these cases an appropriate parametrisation of the functional renormalisation group flows in terms of the relevant degrees of freedom as well as a suitable regulator choice is pivotal for the resolution of the system.
In the present talk I discuss generalised fRG flows for generating functionals with an adaptive reparametrisation of the theory at hand, both for the Wilsonian effective action [1] and for the 1PI effective action [2]. These generalised flows are used for the computation of complex actions [4] (Lee-Yang zeros) as well as for flowing fields [5], see the talk of F. Ihssen. This setup can be accompanied with a flowing renormalisation of fRG flows [3]. Besides allowing for an adaptive renormalisation, renormalised fRG flows also accommodates regulators without an ultraviolet regularisation such as the Callan-Symanzik regulator. The latter regulator allows for a Lorentz-invariant regularisation of QFTs and also respects non-relativistic space-time symmetries. This is a natural setting for computing real-time correlation functions and I will report on first results in scalar theories and quantum gravity [3].

References

[1] F. J. Wegner, Journal of Physics C: Solid State Physics 7, 2098 (1974).
[2] J. M. Pawlowski, Annals of Physics 322 12, 2831-2915 (2007)
[3] J. Braun et al., 2206.10232 [hep-th]; J. Fehre et al., PRL 130 (2023) 081501; J. Horak et al., 2303.16719 [hep-th]
[4] F. Ihssen and J. M. Pawlowski, 2207.10057 [hep-th]
[5] F. Ihssen and J. M. Pawlowski, in preparation

Inference and the inverse problem from a field theory and renormalisation group perspective

A. Rançon[1]

[1] *Laboratoire PhLAM, Université de Lille, France*

After reviewing the inverse problem and inference, i.e. how one can infer the probability law (or Hamiltonian) from observables (e.g. correlation functions), I will discuss the challenges faced by standard field theory and functional RG approaches.

Renormalization Group Flows as a Tool for Rigorous QFT and Statistical Mechanics

M. Salmhofer[1]

[1]*Institut für Theoretische Physik, Universität Heidelberg, Heidelberg, Germany*

This talk will give an overview how the flow equations of the renormalization group can be used to give rigorous proofs about convergence and properties of effective actions and correlation functions of quantum field theories and statistical mechanical models. In some cases, RG flows make it possible to construct models mathematically in a relatively simple way. Recent results in this direction and some open questions will be discussed.

Real Scalar Field Shear Viscosity using the Functional Renormalization Group

S.Flörchinger[1], L.Heyen[2] and <u>T.Stötzel</u>[1]
[1]Theoretisch-Physikalisches Institut, Jena, Germany
[2] Institut für Theoretische Physik, Heidelberg, Germany
Email: tim.stoetzel@uni-jena.de

We study the emergence of the shear viscosity transport coefficient of a real, massive scalar field with quartic coupling in the symmetric phase.
In this work, we derive an FRG flow equation for the transport coefficient in the framework of linear response theory. We propose a truncation which allows for a non-vanishing flow the shear viscosity. Dissipation will be incorporated by the introduction of a thermal width. This leads us to a new damping term in the action and a modified interaction term. The real time observables are computed using the imaginary time formalism and analytic continuation.

Spontaneous versus explicit replica symmetry breaking in the theory of disordered systems

G. Tarjus

LPTMC, CNRS & Sorbonne University, Paris, France

The presence of quenched disorder in condensed-matter systems leads on the one hand to new phenomena, such as multiplicity of states, avalanches, droplet excitations, etc., and on the other to technical difficulties due to the intrinsic inhomogeneity of the medium. The latter can be formally handled through the use of "replicas" of the original system and the consideration of disorder-averaged quantities. How can one then keep track of the multiplicity of states or of singular large-scale events such as avalanches? Several frameworks have been proposed: the spontaneous breaking of replica symmetry, mostly used in mean-field models, and the appearance of a nonanalytic field dependence of the renormalized effective action, studied within the functional renormalization group. I will discuss the two formalisms and their connection.

Effective theory of large scale structure

N. Tetradis

Department of Physics, University of Athens, Greece

Treating dark matter at large scales as an effectively viscous fluid provides an improved framework for the calculation of the density and velocity power spectra compared to the standard assumption of an ideal pressureless fluid. We discuss how this framework can be made concrete through a coarse-graining procedure.

We consider modes with momenta below a scale k_m for which the dynamics is only mildly non-linear. The leading effect of modes above that scale can be accounted for by effective non-equilibrium viscosity and pressure terms. Concrete expressions for these terms with no free parameters, except the matching scale k_m, are derived. Two-loop calculations of the matter power spectrum in the viscous theory lead to excellent agreement with N-body simulations up to scales k=0.2h/Mpc.

The framework can be extended by describing dark matter in terms of a one-particle irreducible effective action at the characteristic scale k_m and a loop expansion below this scale, based on effective propagators and vertices. The (inverse) propagators contain the effective viscosity and sound velocity, while the effective vertices also arise from the integration of high-momentum modes. The bispectrum of density perturbations is computed within a one-loop approximation in the effective theory. A slightly improved agreement with N-body simulations is obtained.

The framework can be further extended by deriving the functional renormalization group flow of the effective action of cosmological large-scale structures. Non-perturbative approximate solutions are obtained by truncating the effective action to a finite number of terms. RG flow equations for the scale dependence of the effective viscosity and sound velocity can thus be derived.

References

- D. Blas, S. Floerchinger, M. Garny, N. T., U. Wiedemann
  Large scale structure from viscous dark matter
  arXiv:1507.06665[astro-ph.CO], JCAP 1511, 049 (2015)
- S. Floerchinger, M. Garny, N. T., U. Wiedemann
  Renormalization-group flow of the effective action of cosmological large-scale structures
  arXiv:1607.03453[astro-ph.CO], JCAP 1701 no.01, 048 (2017)
- S. Floerchinger, M. Garny, A. Katsis, N. T., U. Wiedemann
  The dark matter bispectrum from effective viscosity and one-particle irreducible vertices
  arXiv:1907.10729[astro-ph.CO], JCAP 1909 no.09, 047 (2019)

Phase transitions in active matter

M. Tissier

[2] *Sorbonne Université, Paris, France*
matthieu.tissier@sorbonne-universite.fr

In the past few decades, statistical mechanics has been used to discuss the behavior of active matter. This term is used to coin various situations where a macroscopic number of self-propelled agents interact together. In this talk, I will discuss two such situations: the incompressible polar active matter and chemotaxis.

References

[1] Riccardo Ben Alì Zinati, Marc Besse, Gilles Tarjus, and Matthieu Tissier Phys. Rev. E **105,** 064605 **(2022)**

[2] Saeed Mahdisoltani, Riccardo Ben Alì Zinati, Charlie Duclut, Andrea Gambassi, and Ramin Golestanian, Phys. Rev. Research **3**, 013100 (2021)

Merging dynamical mean-field theory and functional renormalization group for correlated electrons: A stepping-stone for mastering the nonperturbative regime in two dimensions

A. Toschi

Institute for Solid State Physics, TU Wien, Austria
(email: toschi@ifp.tuwien.ac.at)

The combination of dynamical mean-field theory (DMFT) and functional renormalization group (fRG), within the approach coined DMF^{2}RG [1], is designed to overcome the major limitations of the two schemes considered separately, namely the restriction to purely local correlations of the DMFT and the perturbative nature of (truncated) fermionic fRG implementations. In a nutshell, the fRG-flow of the DMF^{2}RG is constructed to start from the DMFT solution of the problem under consideration, which has intrinsically built-in all the nonperturbative information about local moment formation, Kondo screening as well as Mott metal-insulator transitions, and to gradually add upon it the missing information about nonlocal correlations in all scattering channels via the fRG-flow. In this talk, I will discuss how nonperturbative physical processes are actually encoded [2] in the DMFT input, namely in its self-energy and two-particle vertex functions, highlighting the fundamental role that the strong intertwining [3] of different scattering channels plays for correctly capturing the physics of the local moment formation and enabling the strong-coupling description of Mott transitions. I will then show, by hands of explicit DMF^{2}RG calculations [4] for the 2D Hubbard model at half-filling, how the DMFT information on nonperturbative local correlations is preserved by the fRG flow, allowing to extend its applicability up to values of the Hubbard interaction significantly larger than the bandwidth, at least for temperatures higher than the ordering temperature of the DMFT itself. Finally, I will sketch how the recently introduced [5] multiloop extension of the fRG-flow [6] might be incorporated in the DMF^{2}RG algorithm, perspectively allowing to access the most challenging lowest-temperature regimes with extended magnetic fluctuations, consistent with the Mermin-Wagner theorem.

References

[1] C. Taranto *et al.*, PRL **112**, 196402 (2014).
[2] P. Chalupa *et al.,* PRL **126**, 056403 (2021).
[3] S. Adler *et al.,* arXiv:2212.09693.
[4] P. Bonetti *et al.,* PRR **4**, 013034 (2022).
[5] F. Kugler et al., PRL **120**, 057403 (2018).
[6] A. Tagliavini *et al.,*SciPost.Phys. **6**, 009 (2019); C. Hille *et al.,* PRR **2**, 033372 (2020); P. Chalupa-Gantner et al., PRR 4, 023050 (2022).

Probabilistic Cellular Automata for Fermionic Quantum Field Theories

C. Wetterich

Heidelberg University, Germany

Occupation numbers of fermions take the values zero or one - they can be associated with the bits of an automaton. The updating of a probabilistic automaton is characterised by a step evolution operator acting on a wave function, whose square is the probability distribution for bit configurations. Certain discretized fermionic quantum field theories have the same step evolution operator and wave function as a suitable automaton. All observables are identical to the ones of the probabilistic automaton. This identifies a genuine quantum theory with a classical probabilistic theory, with far reaching conceptual consequences. All quantum laws or axioms follow from classical probability theory. We describe explicitly probabilistic automata for simple fermionic models with interactions in two dimensions. They can be formulated as a particular type of Ising models. Finding the continuum limit of such models is a great challenge that may require to adapt functional renormalization to situations where boundary conditions remain relevant for the behavior in the bulk.

RG-flow of the Effective Action of Cosmological Large-scale Structures

Urs Achim Wiedemann

CERN, Meyrin, Switzerland

The microscopic formulation of cosmological large scale structure formation is based on a collisionless Vlasov-Boltzmann equation which numerical N-body simulations solve down to small scales where baryonic effects become important. For sufficiently large scales where the dynamics is only weakly non-linear, a lot of work has gone in recent years into complementing N-body simulations with advanced analytical techniques. This is motivated not only by the general desire of understanding complex simulations in simple analytical terms, but also by efforts of scanning the relevant range of initial conditions while circumventing CPU-intensive simulations. Here, we recall a first attempt of applying the functional renormalization group techniques to this problem. Can effort will be made to highlight the current limitations of this program and to discuss of how they could be overcome.

Computational fluid dynamics and the fRG

N. Wink[1]

[1]*Institut für Kernphysik, TU Darmstadt*

The talk reviews the application of computational fluid dynamics techniques to flow equations. Particularly, on the deep connection between RG flows and the convection dominated nature of the resulting PDEs in a derivative expansion. These properties, as well as their interplay with phase transitions, are made explicit by the example of O(N) theories in various variations. Furthermore, numerical aspects of the RG-time evolution itself and the extension beyond simple models and truncations will be discussed.

The Use of Conformal Invariance in the Non-Perturbative Renormalisation Group Framework

N. Wschebor

[1]*Universidad de la República, Montevideo, Uruguay*

It will be presented how the inclusion of information coming from conformal invariance can improve the results obtained in the study of critical phenomena in the framework of the Non-Perturbative or Functional Renormalisation Group. The fixed point condition of NPRG equations is identical to the Ward identity for scale invariance in the presence of an infrared regulator, but a large number of critical phenomena not only exhibit scale invariance but are invariant under the full conformal group. Ward identities for special conformal transformations will be derived and their link with scale invariance will be analysed showing that the use of conformal invariance allows to improve the results coming exclusively from scale invariance. The universality class of the three-dimensional Ising model will be used as a concrete example.

Abstracts of Posters

(in alphabetical order)

An fRG Analysis of the Extended Hubbard Model on the Square and Triangular Lattices

A. Al-Eryani[1], S. Heinzelmann[2], K. Fraboulet[2] and S. Andergassen[2]

[1]*Institute for Theoretical Physics III, Ruhr-University Bochum, D-44801 Bochum, Germany*

[2] *Institut für Theoretische Physik and Center for Quantum Science, Universität Tübingen, Auf der Morgenstelle 14, 72076 Tübingen, Germany*

The functional renormalisation group has played an important role in investigating strongly correlated systems in condensed matter. To aid for a quantitative investigation, a full, yet efficient, momentum [4] and frequency treatment [5] of the vertex and the self-energy is needed. In the context of extended interactions however, the arguments for the asymptotic decay for the vertex used in [5] no longer hold.

We show how the extended interactions can be implemented in a multi-channel partially bosonised fRG flow equations [2, 1] (the so called Single Boson Exchange fRG flow equations). We find that even with extended interactions, the part of the vertex responsible for the multi-boson exchanges is negligible - similar to what has been found for local interactions in [3].

Finally, we present a quantitative analysis of the extended Hubbard model on square and triangular geometries, at half-filling and at finite doping.

References

[1] F. Krein et al., Phys. Rev. B 100, 155149 (2019)
[2] P. M. Bonetti et al., Phys. Rev. Research 4, 013034 (2022)
[3] K. Fraboulet et al., Eur. Phys. J. B 95, 202 (2022)
[4] J. Lichtenstein et al., Comp. Phys. Comm. (2017)
[5] N. Wentzell et al., Phys. Rev. B 102, 085106 (2020)

Quantum Einstein Cubic Gravity

D. Litim[1] and G. Assant[1]

[1] *Department of Physics and Astronomy, University of Sussex, Brighton, BN19QH, U.K.*

The asymptotic safety scenario, according to which a quantum field theory of gravity is made non-perturbatively renormalizable via an interacting renormalization group fixed point, is considered a viable contender for a theory of quantum gravity. Promisingly, such fixed points are found in general relativity and many higher curvature extensions of gravity. Generic higher order theories display 4^{th}-order propagating degrees of freedom often spoiling unitarity, e.g. Stelle gravity. They also often entail black hole solutions very different from those known in Einstein gravity. Interestingly, however, it was recently noticed that some higher-curvature extensions of gravity can be found which have the exact same linear spectrum as in ordinary Einstein gravity. The virtue of these new “Einsteinian gravities” is that they allow for higher curvature interactions, as necessary for asymptotically safe fixed points, but avoid the dangerous 4th order propagating degrees of freedom. I review the main ideas of Einsteinian gravities, and report on the search for interacting UV fixed points using the renormalisation group. Results include UV scaling dimensions, the phase diagram, and concrete UV-IR connecting trajectories. Implications for quantum black holes in Einstein cubic gravities are indicated as well.

Renormalization group and probability theory

I. Balog[1] ,A. Rançon[2] ,B. Delamotte[3]

[1]Institute of Physics, Bijenička cesta 46, HR-10001 Zagreb, Croatia
[2] Univ.Lille, CNRS, UMR 8523 – PhLAM – Laboratoire de Physique des Lasers Atomes et Molécules, F-59000 Lille, France
[2] Laboratoire de Physique Théorique de la Matière Condensée, UPMC, CNRS UMR 7600, Sorbonne Université, 4, place Jussieu, 75252 Paris Cedex 05, France

The question of understanding the probabilistic interpretation [1] of the renormalization group (RG) has been a topic of ongoing research for decades, dating back to the inception of the field in the 1970s. Recently [2], we have developed a new method that utilizes the effective average action formalism to devise a flow equation for the rate function **I(m)**. This function determines the scaling function of the critical distribution of the order parameter **P(m)**, with **I(m)=-ln(P(m))**.

We show that **I** is a universal function, characterized by the parameter **ζ=ξ/L**, which describes the approach to criticality. We have validated our method through Monte Carlo simulations, which demonstrate a close alignment of the rate functions for different ζ values with those determined from the RG method. Furthermore, our analysis shows that for all cases when **ζ>1**, the shape of the rate function is largely similar, yet not identical, to the shape of the fixed point (dimensionless) effective potential, featuring concavity near the origin. We also discuss extensions of our work to momentum-dependent quantities and its implications.

References

[1] G. Jona-Lasinio: Il Nuovo Cimento, 26, 99 (1975).
[2] I. Balog, A. Rançon, and B. Delamotte, Phys. Rev. Lett. 129, 210602 (2022).
[3] J. Berges, N. Tetradis, and C. Wetterich, Phys. Rep. 363, 223 (2002).

Functional renormalization of the spin-1 Bose gas

Alexander Baum,[1] **A. N. Mikheev**,[1,2] **N. Rasch**,[1] **and T. Gasenzer**[1,2]

[1]*Kirchhoff-Institut für Physik, Ruprecht-Karls-Universität Heidelberg,*
Im Neuenheimer Feld 227, 69120 Heidelberg, Germany
[2]*Institut für Theoretische Physik, Ruprecht-Karls-Universität Heidelberg,*
Philosophenweg 16, 69120 Heidelberg, Germany

We investigate the spin-1 Bose gas at zero temperature using functional renormalization group techniques. We derive explicitly the flow equations in the polar phase of the system, in a local-potential approximation including anomalous scaling. From the solutions to these flow equations we calculate the spectrum and superfluid fraction of the system. In a further analysis we aim to apply the same framework to the more complicated easy-plane phase, with the goal to describe the second-order phase transition between the polar and easy-plane phases.

Entanglement and Expansion

K. Boutivas[1], G. Pastras[2,3] and N. Tetradis[1]

[1]Department of Physics, University of Athens, Zographou 157 84, Greece
[2]Institute of Nuclear and Particle Physics, NCSR 'Demokritos', Aghia Paraskevi 15310, Greece
[3]Laboratory for Manufacturing Systems and Automation, Department of Mechanical Engineering and Aeronautics, University of Patras, Patra 26110, Greece

In a recent paper[1] we studied the entanglement entropy resulting from tracing out local degrees of freedom of a quantum scalar field in an expanding universe. During inflation, the field modes that get stretched beyond the horizon evolve into increasingly squeezed states. We argue that this effect results in the continuous growth of entanglement entropy, proportionally to the total duration of inflation, as successive modes cross the horizon. We show that the entanglement entropy is preserved during a subsequent radiation or matter dominated era, so that it may be significant for today's universe. We demonstrate these features in a toy model of a scalar field in 1+1 dimensions. We also present preliminary results for a 3+1 dimensional free field theory. They explicitly display a volume dependence of the entanglement entropy during the radiation-dominated era, violating the well-known area law in a static background.

References

[1] K. Boutivas, G. Pastras, N. Tetradis, arXiv:2302.14666 [hep-th]

Renormalization flow analysis for two Pomeron/Odderon

L. Cancino[1] and C. Contreras[1]

[1]*Departamento de Física, Universidad Técnica Federico Santa María, Valparaíso, Chile.*

In recent years, the difference in the collision processes pp and pp at high energies were measured in the TOTEM and DØ experiments. They found that they differ and this can be explained by the exchange of a particle composed of an odd number of gluons called Odderon [1]. A model to study the critical properties of this particle and the Pomeron, a state with an even number of gluons, has been proposed by Bartels, Contreras, and Vacca using the effective Reggeon Field Theory (RFT) [2, 3]. Furthermore, they calculated the spectrum of the Pomeron with a Wilsonian´s IR regulator by finding a set of states of the Pomeron [4]. Knowing the critical behaviour of the interaction of these fields in the IR and UV limits is relevant and for this study, we will use non-perturbative methods of the functional renormalization group type [5]. In this paper, we start with the effective action of a Reggeon field theory for the Pomeron states ψ_i [2], where in our case we will consider two interacting fields (i.e., i = 1, 2):

$$\Gamma\left[\psi_i, {\psi_i}^{\dagger}\right] = \int d^D x\, d\tau Z_i \left(\tfrac{1}{2}\psi_i^{\dagger}\partial_\tau\psi_i - \alpha_i'\psi_i^{\dagger}\nabla^2\psi_i\right) + m\left(\psi_1\psi_2^{\dagger} + \psi_2\psi_1^{\dagger}\right) - \mu_i\psi_i^{\dagger}\psi_i + V\left[\psi_i, \psi_i^{\dagger}; \lambda_n\right],$$

where μ_i and α_i' are the 'Reggeon intercept' and the 'Reggeon slope'; $V\left[\psi_i, \psi_i^{\dagger}; \lambda_n\right]$ contains all the interactions between the fields described by the coupling constants λ_n, as a first approximation we will consider interactions up to third order in the fields (i.e., we will have 6 λ's). The critical properties of the theory are given by its functional renormalization group equations (FRGE) derived from the Wetterich equation [5]:

$$\partial_t \Gamma[\psi_i] = \tfrac{1}{2} Tr\left[\left(\Gamma_k^{(2)}[\psi_i] + R_k\right)^{-1} \dot{R}_k\right],$$

where R_k is the IR regulator and $\Gamma_k^{(2)}$ is the second functional derivative of the effective action. This equation gives a set of non-linear differential equations of the coupling constants. In this work, fixed points of ten non-linear differential functions are found and calculated by numerical methods [6]. The evolution of the couplings near these fixed points is studied, searching for a connection between different regions (associated with poles of the same Regge trajectory) in the theory space.

References

[1] DØ and TOTEM Collaboration, Phys. Rev. Lett **127** (2021), 0620032 and Eur. Phys. J. C **2** (2019), 103

[2] J. Bartels, C. Contreras and G. P. Vacca, JHEP **1603** (2016), 201.

[3] J. Bartels, C. Contreras and G. P. Vacca, Phys. Rev. D **95** (2017), 014013.

[4] J. Bartels, C. Contreras and G. P. Vacca, Journal of High Energy Physics, **1** (2019), 1-46.

[5] C. Wetterich, Phys. Lett. B **301** (1993) 90-94.

[6] Li G., Zeng Z. (2008), IEEE International Conference On Computational Intelligence And Security, **vol 1**, 20–23, 2008

The Flat Phase of Polymerized Membranes and Polymerized Membrane Bilayers

Louise Delzescaux

[1]*Sorbonne University, Paris, France*

Phase transition is a fundamental concept in physics that occurs when a system undergoes a transition between two states. This phenomenon is present in different areas of physics such as condensed matter or particle physics. The Mermin Wagner Theorem states that there is no symmetry breaking in continuous system with short-range interactions of dimension equal or less than 2. However, polymerized membranes are 2D systems that display a crumpling transition between a high-temperature, crumpled, phase and a low temperature, flat, phase.

In this poster, we will discuss the flat phase of polymerized membranes - which, for instance, is relevant for graphene - and present our use of the non-perturbative renormalization group to study the fluctuations and behavior of this phase. Additionally, we introduce polymerized membrane bilayers, the system being studied in my ongoing Ph.D. research

Symmetry Breaking in Dense QCD Matter

T. Dörnfeld[1]

[1] *Institute for Nuclear Physics - Theory Center, Darmstadt, Germany*

We discussed aspects of the Silver-Blaze property with respect to dense systems in a field theoretical approach. We looked at the widely used derivative expansion of the effective action and how we need to restrict the analysis in order to remain invariant under Silver-Blaze transformations. We framed this analysis with respect to dense systems where Cooper instabilities emerge and render the overall behaviour of the system. An explicit isospin imbalance has been implemented into the approximation scheme and the regularisation of the theory. Thus, up and down quarks could now be distinguished as different fermions.

By consciously imbedded (physical) flaws in the analysis of the expansion point, we showed the necessity of violating the Silver-Blaze symmetry in order to recover the BCS-like scaling behaviour of observables, like the critical scale of diquark condensation. On the foundation of Silver-Blaze-symmetry breaking and the presence of Cooper instabilities, we introduced a new class of three-dimensional, spatial regulators suitable to screen infrared divergences and, furthermore, gap those instabilities at the Fermi surface over the RG flow. This momentum-gap was first introduced as a sharp cutoff, but is also applicable to other regulator shape functions. The new class can be simplified to a standard class of regulator conventionally used in Functional RG studies. We emphasise that the new regulator class is not suited for studies at small chemical potentials as benchmark for the Silver-Blaze property in this regime. It is also a valid class in the limit of vanishing chemical potential in the presence of a finite mass.

It has been shown successfully that the running of the mass parameter as well as the diquark gap have been generalised to finite isospin imbalances. Moreover, could we validate the behaviour of the critical scale at which the $U_V(1)$-symmetry breaks down to fit our expectations of BCS-like scaling. Explicitly resolved isospin imbalances showed that diquark condensation breaks down for sufficiently large imbalances and at the same time adequately small quark chemical potentials. This agrees with our expectations and with the discussion on Fermi spheres. Increasing both degrees of freedom yielded a finite critical scale over the entire range of imbalances. With respect to the presented framework, the behaviour of the critical scale at and around the upper boundary of the physically allowed domain of imbalances needs to be seen controversially, due to the used flavour-density approximation.

References

1. T. Dörnfeld, *Symmetry Breaking in Dense QCD Matter,* https://doernfeld.eu/symmetry-breaking-in-dense-qcd-matter/, 2021
2. J. Braun, T. Dörnfeld, B. Schallmo, and S. Töpfel, *Renormalization group studies of dense relativistic systems*, Phys. Rev. D 104, 096002 – Published 2 November 2021

Quantum transport of strongly correlated fermions

Tilman Enss[1]

[1]*Institute for Theoretical Physics, University of Heidelberg, Germany*

Fermionic transport at strong interaction often cannot be understood by fermionic quasiparticles alone. We present a theoretical framework for quantum transport that takes into account strong local correlations of fermion pairs. In attractively interacting ultracold Fermi gases, these contact correlations make substantial contributions to viscous, thermal and sound transport. We calculate the transport coefficients both analytically in the virial expansion and numerically using the Luttinger-Ward framework. By analyzing the real-frequency spectral properties of the particles and pairs, we derive an effective kinetic theory for the bulk viscosity based on pinch singularities. We compare our results with recent sound diffusion measurements in the quantum critical regime and discuss the role of the quantum scale anomaly in the dynamics of two-dimensional Fermi gases.

References

[1] T. Enss, *Bulk viscosity and contact correlations in attractive Fermi gases,* Phys. Rev. Lett. **123**, 205301 (2019).

[2] K. Fujii and T. Enss, *Bulk viscosity of resonantly interacting fermions in the quantum virial expansion,* Ann. Phys. (2023 in press), arXiv:2208.03353.

[3] B. Frank, W. Zwerger, and T. Enss, *Quantum critical thermal transport in the unitary Fermi gas,* Phys. Rev. Research **2**, 023301 (2020).

[4] P. A. Murthy, N. Defenu, L. Bayha, M. Holten, P. M. Preiss, T. Enss, and S. Jochim, *Quantum scale anomaly and spatial coherence in a 2D Fermi superfluid,* Science **365**, 268-272 (2019).

Linear and nonlinear realizations of chiral symmetry

J. Eser[1]

[1] *Université Paris-Saclay, CNRS, CEA, Institut de physique théorique, 91191 Gif-sur-Yvette, France*

I discuss the generation of low-energy couplings within effective models of the strong interaction [1-3], which is accompanied by the transition from linear to nonlinear realizations of chiral symmetry in the framework of the FRG. The validity ranges and appropriate renormalization scales of effective models including higher derivative interactions are determined from the analysis of quantum fluctuations. I outline possible phenomenological applications of these principles to pion-pion scattering [4] and the nuclear equation of state at the interface between chiral perturbation theory and FRG-improved linear models.

References

[1] N. Cichutek, F. Divotgey, and J. Eser, PRD **102** 3, 034030 (2020).
[2] F. Divotgey, J. Eser, and M. Mitter, PRD **99** 5, 054023 (2019).
[3] J. Eser, F. Divotgey, M. Mitter, and D.H. Rischke, PRD **98** 1, 014024 (2018).
[4] J. Eser and J.-P. Blaizot, PRD **105** 7, 074031 (2022).

Lower Critical Dimension in the ϕ^4 Theory

Lucija Nora Farkaš, Gilles Tarjus, Ivan Balog

We study the transition in a ϕ^4 scalar field theory in the vicinity of the lower critical dimension. Differently than in the O(N) model where the Goldstone excitations cause the onset of the lower critical dimension at d=2 [1], in the case of discrete symmetry the lower critical dimension is defined by the condition that the field does not rescale, i.e. $d-2+\eta\to 0$. We examine the FRG approach to this problem using increasingly complex nonperturbative approximation schemes. We find that upon the approach to the lower critical dimension d_l, the fixed point solution develops a boundary layer which width goes to 0. The presence of the boundary layer causes the minimum of the potential to diverge proportionally to $\rho_{min}=\phi^2/2\propto ln(1/(d-2+\eta))$ leading to the conclusion that $T_c\propto \frac{1}{ln(1/(d-2+\eta))}$. This, at first sight peculiar finding, can readily be interpreted using the results by Bruce and Wallace [2], who constructed a droplet excitations theory in $d=1+\epsilon$ dimensions. The singular dependence of the field renormalization exponent and the dimensionality that they uncovered is such that our finding leads to $T_c\propto d-1$ as expected.

Our work is relevant for the description of a phase transition which is dominated by instantonic excitations, which are rare when temperature is low and are localized in space. We aim to answer the questions about how they propagate from the ultra-violet to the infra-red limit and hope to uncover clues of how they can be identified from the renormalization group.

References

[1] N.D. Mermin and H. Wagner: Phys. Rev. Lett. 17 1133 (1966)
[2] A. D. Bruce and D. J. Wallace: J. Phys. A: Math. Gen. 16 1721 (1983)

Fate of the axial anomaly at finite temperature

G. Fejos and A. Patkos

Institute of Physics, Eotvos University, Budapest, Hungary

We investigate the role of mesonic fluctuations in the three flavor linear sigma model with regard to the axial anomaly using the functional renormalization group formalism at finite temperature. We find that mesonic fluctuations tend to strengthen the anomaly at finite temperature. The effect is obtained by the calculation of the chiral condensate dependence of the Kobayashi--Maskawa--t 'Hooft coupling, which is found to be monotonically decreasing with respect to the condensate. By implementing instanton contributions via the "bare" anomaly parameter defined at the UV scale, we also investigate the interplay between the two competing effects.

References

[1] G. Fejos and A. Patkos, Phys. Rev. D**105**, 096007 (2022).
[2] G. Fejos, Symmetry **13**(3), 488 (2021).

Multiloop single-boson-exchange fRG and its application to the two-dimensional Hubbard model

K. Fraboulet[1], S. Heinzelmann[1], A. Al-Eryani[2], P. M. Bonetti[3], D. Vilardi[3], A. Toschi[4] and S. Andergassen[1]

[1]Institut für Theoretische Physik and Center for Quantum Science, Universität Tübingen, Auf der Morgenstelle 14, 72076 Tübingen, Germany
[2] Institute for Theoretical Physics III, Ruhr-University Bochum, D-44801 Bochum, Germany
[3] Max Planck Institute for Solid State Research, Heisenbergstrasse 1, D-70569 Stuttgart, Germany
[4] Institute of Solid State Physics, TU Wien, 1040 Vienna, Austria

The multiloop functional renormalization group (fRG) was recently proposed as a refined way to capture effects of the three-particle vertex within the fRG approach, thus improving the canonical 1-loop fRG that is already established as a powerful tool to study many-electron systems. In this poster, we discuss a first application of the multiloop single-boson-exchange (SBE) fRG, i.e. the merging of the SBE formalism (that allows for partial bosonization without ambiguity) with the multiloop fRG. More specifically, we will present results for the two-dimensional Hubbard model on a square lattice, both at half filling and at finite doping. We expect this fRG formulation to yield improved convergence in the context of both standard fRG and DMF^{2}RG, which uses dynamical mean field theory results as initial conditions for the fRG flow.

References

[1] F. Krien et al., Phys. Rev. B 100, 155149 (2019)
[2] P. M. Bonetti et al., Phys. Rev. Research 4, 013034 (2022)
[3] M. Gievers et al., Eur. Phys. J. B 95, 108 (2022)
[4] K. Fraboulet et al., Eur. Phys. J. B 95, 202 (2022)

Speed of Sound of strong-interaction matter at supranuclear densities

Jens Braun[1, 2], Andreas Geißel[1], and Benedikt Schallmo[1]

[1]*Institut für Kernphysik, Technische Universität Darmstadt, Darmstadt, Germany*
[2]*GermanyExtreMe Matter Institute EMMI, GSI, Planckstraße 1, Darmstadt, Germany*

Towards the equation of state of neutron stars, we present results for the zero-temperature thermodynamics of strong-interaction matter at high densities which have been obtained based on first-principles functional Renormalization Group studies. In particular, we discuss gluon vacuum polarization effects on the equation of state and the speed of sound in a (semi-)perturbative manner. Eventually, we present consistent constraints for the speed of sound at supranuclear densities by taking into account results from studies based the existence of a (color-) superconducting gap.

References

[1] J. Braun et al., arXiv: 2206.06328

Investigating the Quark-Meson-Vector meson model with functional renormalisation group techniques

Nicolas Hendricks,[1] Friederike Ihssen,[1] Jan M. Pawlowski,[1,2] and Franz R. Sattler[1]

[1] *Institut für Theoretische Physik, Universität Heidelberg, Philosophenweg 16, 69120 Heidelberg, Germany*

[2] *ExtreMe Matter Institute EMMI, GSI, Planckstr. 1, 64291 Darmstadt, Germany*

We apply the functional renormalisation group to a low energy effective model of quantum chromodynamics, the Quark-Meson-Vector meson model. The model is analysed at finite tempearature and quark chemical potential, where we also include an explicit coupling between the mesons and the vector mesons. Through the usage of a 3D Litim regulator we can give an analytic expression for the part of the flow equation that describes the coupled condensates. We investigate the behaviour of the vector meson masses with varying scales when initially using a quadratic potential dependency for the vector meson and shine light on what is expected from the theory, especially the Silver-Blaze property of QCD.

On the QCD diffusion coefficient

M. Horstmann[1]

[1]*Institute for Theoretical Physics, Heidelberg, Germany*

The quantum chromodynamics flavour diffusion coefficient D_f is computed for a light flavour quark current via the Kubo formula. The contributing diagrams of the quark current are computed with the use of the functional methods. Further with the use of the Källen-Lehmann spectral representation for the full quark propagator and the Matsubara formalism an effective formula for the quark diffusion channel spectral function is determined, that is used to compute the diffusion coefficient. This procedure shows, that with the vacuum spectral function given in [1] the diffusion coefficient D_f vanishes at any temperature. Next, a finite temperature quark spectral function gets modeled using the results from [2] by fitting a Breit-Wigner pole as a spectral function. With the fit parameters a transport peak gets computed, which influence of the diffusion coefficient is getting studied.

References

[1] J. Horak, J. M. Pawlowski, N. Wink, “On the quark spectral function in QCD”, 2210.07597 (2022)

[2] F. Gao, J. M. Pawlowski, “Phase structure of 2+1-flavour QCD and the magnetic equation of state”, 2112.01395 (2021)

Numerical fluid dynamics for FRG flow equations

A. Koenigstein[1] and M. J. Steil[2]

[1]*TPI, Friedrich-Schiller University Jena & ITP Goethe University Frankfurt a. M.*
[2] *Institute for Nuclear Physics, Technical University Darmstadt*

We show that analogies exist between FRG flow equations and (numerical) fluid dynamics. We apply methods from computational fluid dynamics to FRG flow equations and test the precision of these methods by comparison with exact reference solutions. For this purpose we use (0+0)-dimensional QFTs which are often a perfectly suited testing ground for (non-)perturbative methods from statistical physics and QFT.
Leveraging this framework we study different aspects of RG flows including truncations, irreversibility, and RG consistency. Most of our findings can be generalized to QFTs in nonzero spacetime dimensions.

References

[1] A. Koenigstein, M. J. Steil, N. Wink, E. Grossi, J. Braun, M. Buballa, and D. H. Rischke, Phys. Rev. D 106, 065012.
[2] A. Koenigstein, M. J. Steil, N. Wink, E. Grossi, and J. Braun, Phys. Rev. D 106, 065013.
[3] M. Steil and M. J. Steil, Phys. Rev. D 106, 065014.
[4] E. Grossi and N. Wink, arXiv: 1903.09503 [hep-th].

Holographic Nonlinear Finance and its connections to the Microeconomic Behavioral Structures

Akitoshi Okutsu[1]

[1] *University of Tokyo, Department of Physics, Tokyo, Japan*

Traditional understanding of finance since the seminal paper by Black, Scholes, and Merton in 1973 [1,2] necessitates the martingale condition, in layman's terms the "no risk no gain, no free lunch" condition, or in technical terms the "no arbitrage" as well as the "efficient market" condition, and hinders long-memory, non-Brownian, non-Gaussian behavior in the asset log-returns. However, empirical asset data exhibited fat-tailed, power-law decaying PDF instead of exponentially decays. A Non-Gaussian model was first proposed in the eponymous paper [3] by Mandelbrot et al. with the so-called Levy distribution, which captured fat-tail behaviors well. Concepts of fractal and Hurst exponent were also introduced to quantify fat-tail behaviors. However, the infinite variance of the Levy PDF was unrealistic to simulate the real world. Then, Gençay et al [4] came up with the q-distribution and the non-extensive q-entropy to generalize a broader class of distributions inducing the power-law decays and correlations (No autocorrelation and Gaussian at q=1), so that different time-sections of markets were entangled, and market crashes were more accurately predicted. The Hurst exponent for q-distributions was found out in [5].

For a more microscopic view, a field theoretic analysis of nonlinear finance was done by Y. Nakayama [6] and the Hurst exponent for a dual Reggeon field theory was calculated. The possibility of a path integral formulation for asset prices is seen through the analogy of BSM Option Price differential equation to the nonrelativistic Schrodinger equation under a Galilean transformation. The quadratic potential term spawning harmonic oscillator is analogous to the noise-creating Wiener process PDF. The correlation function of the log-rescaled asset price was calculated using Holography, a string-theoretic concept in which one simply uses EoMs in the bulk of a higher dimension to derive correlation functions in strongly coupled systems on the boundary. However, none of the above is not ab initio unlike Agent Based Models (ABM), which describe microeconomic behaviors and dynamics, e.g. the hierarchical model and the cellular automata. I present a possible connection of holographic finance and ABMs through the MERA entanglement structure.

References

[1] Black F. et al., *Journal of Political Economy* Vol. 81, No. 3, pp. 637-654 (1973)

[2] Merton C. *The Bell Journal of economics and management science*, 141-183 (1973)

[3] Mandelbrot B. *Springer New York*, 371-418, (1997).

[4] Gençay R et al., *Journal of Empirical Finance* 17.2, 270-282, (2010).

[5] Liu L. et al, *Computers & Mathematics with Applications* 79.6, 1802-1812 (2020).

[6] Nakayama Y. *International Journal of Modern Physics A* 24.32, 6197-6222, (2009).

Investigating strong new physics with functional methods

Á. Pastor-Gutiérrez[1]

[1]*Max-Planck-Institut für Kernphysik, Heidelberg, Germany*

Predictions of the Standard Model of particle physics show an astonishing agreement with experimental efforts. However, open questions such as the nature of dark matter, the origin of scales or the excess of matter over anti-matter still remain open. Composite Higgs and alike theories address naturally multiple of these enigmas. In this poster I will focus on how CH models address the flavor puzzle and present results obtained from the rebosonised effective action. This will exemplify how non-perturbative methods such as the Functional Renormalisation Group provide quantitative access to new strong regimes while remain versatile to investigate large theory spaces. Moreover, I will additionally show preliminary results on the properties of chiral condensates in the boundaries of Bank-Zaks windows by means of the rebosonised flow equation. This allows to identify condensates with Higgs-like properties in corners of theory space never accessed before. Finally, I will outline prospects for the determination of resonances and observables by the implementation of engaging scenarios within the Asymptotically Safe SM.

Pseudogap opening in the Hubbard model at strong coupling

Miriam Patricolo[1,3], Sarah Heinzelmann[1], Pietro Bonetti[2], Demetrio Vilardi[2], Sabine Andergassen[1,3]

[1] *Universität Tübingen, Auf der Morgenstelle 14, 72076 Tübingen, Germany*

[2] *Max Planck Institute for Solid State Research, Heisenbergstrasse 1, D-70569 Stuttgart, Germany*

[3] *Technische Universität Wien, 1040 Vienna, Austria*

Using the recently introduced combination of the fRG with the DMFT, coined DMF^{2}RG, we compute the frequency- and momentum-dependent self-energy of the two-dimensional Hubbard model at strong coupling. For this, we extend the single-boson exchange formulation of the fRG for the computation of the self-energy flow with the Schwinger-Dyson equation. This has shown to be essential to capture the pseudogap opening in the weak-coupling regime. We discuss the structure of the flow equations and present numerical results for the self-energy.

References

[1] P. Bonetti M. and A. Toschi and C. Hille and S. Andergassen and D. Vilardi, *Single-boson exchange representation of the functional renormalization group for strongly interacting many-electron systems*,Phys. Rev. Res.,4,American Physical Society, 10.1103/PhysRevResearch.4.013034

[2] F. Krien and A. Valli and M. Capone, *Single-boson exchange decomposition of the vertex function*,Phys. Rev. B,American Physical Society, 10.1103/PhysRevB.100.155149

[3] C. Hille and F. Kugler and C. Eckhardt and Y. He and A. Kauch and C. Honerkamp and A. Toschi and S. Andergassen *Quantitative functional renormalization group description of the two-dimensional Hubbard model*,Phys. Rev. Res.,2,American Physical Society,10.1103/PhysRevResearch.2.033372

[4] W. Metzner and M. Salmhofer and C. Honerkamp and V. Meden and K. Schnhammer *Functional renormalization group approach to correlated fermion systems*,Reviews of Modern Physics,84,American Physical Society (APS)

[5] C. U. Hille, *The role of the self-energy in the functional renormalization group description of interacting Fermi systems*, doi:10.15496/publikation-46212

3+1-dimensional Gauge theories with Luttinger fermions

Holger Gies*[1, 2, 3, 4] and Marta Picciau†[1]

[1] Theoretisch-Physikalisches Institut, Friedrich-Schiller-Universität Jena, D-07743 Jena, Germany
[2] Abbe Center of Photonics, Friedrich-Schiller-Universität Jena, D-07743 Jena, Germany
[3]Helmholtz-Institut Jena, Fröbelstieg 3, D-07743 Jena, Germany
[4]GSI Helmholtzzentrum für Schwerionenforschung, Planckstr. 1, 64291 Darmstadt, Germany

*holger.gies@uni-jena.de
†marta.picciau@uni-jena.de

Luttinger fermions have been of recent interest in condensed matter physics. They were first introduced by J. M. Luttinger in his work on “Luttinger semi-metals”[1].

Extensions and applications of the non-relativistic Luttinger fermions have been discussed in the literature.

We propose and study a new theoretical model of relativistic Luttinger fermions with a quadratic kinetic term in 3+1 space-time dimensions, coupled to a constant electromagnetic field, constituting QED with relativistic Luttinger fermions. We find that a well defined theory requires a Luttinger spinor in a 32-dimensional representation.

Within this theory, we present first results on the one-loop β-function for QED. We also generalize this result to the non-abelian case and compute the one-loop running of the gauge coupling. For these fermions, we observe a strong dominance of the paramagnetic interactions which modify the standard QED (QCD) β-functions. In the non-abelian case, we compute the number of colors needed to preserve the asymptotic freedom of standard QCD.

References

[1] J. M. Luttinger (1956): “Quantum theory of cyclotron resonance in semiconductors”: General theory. Phys. Rev. 102 1030.

Frequency-resolved functional renormalization group for quantum magnetic systems

J. Potten[1] , T. Müller[1] and R. Thomale[1]

[1] *Institute for Theoretical Physics and Astrophysics, University of Würzburg, D-97074 Würzburg, Germany*

Strongly correlated materials are one of the most prolific topics of contemporary condensed matter physics. Within this field, the functional renormalization group (FRG) approach for spin models relying on a pseudo-fermionic description has proven to be a very powerful technique in simulating ground state properties of strongly frustrated magnetic lattices. However, the FRG as well as many other theoretical models, suffer from the fact that they are formulated in the imaginary-time Matsubara formalism and thus are only able to predict static correlations directly. Nevertheless, describing the dynamical properties, especially of magnetic systems is one of the fundamental theoretical challenges, as they are the key to bridging the gap to experimental data from neutron scattering experiments. For the pseudo-fermion FRG, we remedy this shortcoming by establishing a methodical approach based on the Keldysh formalism, originally developed to handle non-equilibrium physics. This novel approach allows for calculating the dynamic properties of spin systems on arbitrary lattices. We can identify the correct low-energy behavior of the dynamic spin structure factors for exemplary nearest neighbor Heisenberg systems. These first results are promising, and extensions of this work might allow for an easy calculation of dynamic properties even for non-equilibrium magnetic systems in the future.

Magnetic systems with discrete anisotropies

A. Chlebicki[1], C. Sánchez[2,3], P. Jakubczyk[1], and N. Wschebor[2]

[1]Institute of Theoretical Physics, Faculty of Physics, University of Warsaw, Warsaw, Poland

[2]Instituto de Física, Facultad de Ingeniería, Universidad de la República, Montevideo, Uruguay

[3]Laboratoire de Physique Théorique de la Matière Condensée, Sorbonne Université, Paris, France

We employ nonperturbative renormalization group to study Z4-symmetric perturbations to the classical XY model in dimensionality $d \in [2,3]$. In d=3 we provide accurate estimates of the eigenvalue y4 associated with the leading irrelevant perturbation and follow the evolution of the physical picture upon reducing the spatial dimensionality from d=3 towards d=2, where we approximately recover the onset of the Kosterlitz-Thouless physics. We analyze the interplay between the leading irrelevant eigenvalues related to O(2)-symmetric and Z4-symmetric perturbations and their approximate collapse for $d \rightarrow 2$.

References

[1] A. Chlebicki, C. A. Sánchez-Villalobos, P. Jakubczyk, & N. Wschebor, (2022). *Physical Review E*, *106*(6), 064135.

Numerical RG-time integration of the effective potential: Analysis and Benchmark[1]

Friederike Ihssen[1] and Franz R. Sattler[1] and Nicolas Wink[2]

[1]Institut für Theoretische Physik, Universität Heidelberg, Philosophenweg 16, D-69120 Heidelberg, Germany
[2] Institut für Kernphysik, Technische Universität Darmstadt, D-64289 Darmstadt, Germany

We investigate the RG-time integration of the effective potential in the functional renormalization group in the presence of spontaneous symmetry breaking and its subsequent convexity restoration on the example of a scalar theory in d = 3. The features of this setup are common to many physical models and our results are, therefore, directly applicable to a variety of situations. We provide exhaustive work-precision benchmarks and numerical stability analyses by considering the combination of different discrete formulations of the flow equation and a large collection of different algorithms. The results are explained by using the different components entering the RG-time integration process and the eigenvalue structure of the discrete system. Particularly, the combination of Rosenbrock methods, implicit multistep methods or certain (diagonally) implicit Runge-Kutta methods with exact or autodiff Jacobians proves to be very potent. Furthermore, a reformulation in a logarithmic variable circumvents issues related to the singularity bound in the flat regime of the potential.

References

[1] Friederike Ihssen, Franz R. Sattler, Nicolas Wink, Numerical RG-time integration of the effective potential: Analysis and Benchmark (2023). arXiv:2302.04736 [hep-th]

Towards the equation of state of color-superconducting strong-interaction matter

J.Braun[1] and J.Stoll[1]

[1]*Institut für Kernphysik, Technische Universität Darmstadt, Darmstadt, Germany*

We investigate the formation of a color superconductor in dense strong-interaction matter as associated with the dynamical generation of a gap in the quark excitation spectrum. To this end, we employ the Wetterich equation in the local potential approximation and solve it with methods borrowed from fluid dynamics, without making any further assumptions about the form of the effective potential. We critically assess regularization and approximation artifacts and present first estimates for the equation of state from our approach.

The fate of chiral symmetry in Riemann-Cartan spaces

Gustavo P. de Brito[1] , Antonio D. Pereira[2,3] and Arthur F. Vieira[1,3]

[1]CP3-Origins, University of Southern Denmark, Campusvej 55, DK-5230 Odense M, Denmark
[2] Institute for Mathematics, Astrophysics and Particle Physics (IMAPP), Radboud University,
Heyendaalseweg 135, 6525 AJ Nijmegen, The Netherlands
[3] Instituto de Física, Universidade Federal Fluminense, Campus da Praia Vermelha, Av. Litorânea
s/n, 24210-346, Niterói, RJ, Brazil

In this work, we explore the possibility of using the interplay between chiral symmetry breaking and gravity to gain some insights on the allowed structures in a gravitational theory. We focus on the Einstein-Cartan formulation, where the spacetime geometry can exhibit non-vanishing torsion. Focusing on a fermionic system coupled to a gravitational background with non-vanishing torsion, we study the impact of a background torsion on the dynamics of 4-fermion (point-like) interactions. In particular, our goal is to understand whether torsion acts in favor or against chiral symmetry breaking, and whether torsion can be responsible for the mechanism of gravitational catalysis. Our findings suggest that spacetime torsion acts in favor of chiral symmetry breaking, but not enough to be a source of gravitational catalysis.

Scalar spectral functions from the functional Renormalisation Group

J. Horak[1] ,F. Ihssen[1], J.M. Pawlowski[1,2], J. Wessely[1] and N. Wink[3]

[1] Institut für Theoretische Physik, Universität Heidelberg, Heidelberg, Germany
[2] ExtreMe Matter Institute EMMI, GSI, Darmstadt, German
[3] Institut für Kernphysik (Theoriezentrum), Technische Universität Darmstadt, Darmstadt, Germany

Email: wessely@thphys.uni-heidelberg.de

We show non-perturbative spectral functions in a scalar φ4 -theory in three space-time dimensions computed via the spectral functional renormalisation group. This approach allows for the direct, manifestly Lorentz invariant computation of correlation functions in Minkowski space-time, including a physical on-shell renormalisation. We present numerical results for the spectral functions of the two- and four-point correlation functions for different values of the coupling parameter and show the evolution of the propagator spectral function on a trajectory in (physical) theory space.

A fixed point can hide another one: the nonperturbative behavior of the tetracritical fixed point of the $O(N)$ models at large N

S. Yabunaka[1] **and B. Delamotte**[2]

[1] *Advanced Science Research Center, Japan Atomic Energy Agency, Tokai, Japan*
[2] *Sorbonne Université, CNRS, Laboratoire de Physique Théorique de la Matière Condensée, LPTMC, Paris, France*

We show that at and below its upper critical dimension, $d < d_{up}$, the critical and tetracritical behaviors of the $O(N)$ models are associated with the same renormalization group fixed point (FP) potential. Only their derivatives make them different with the subtleties that taking their limit and deriving them do not commute and that two relevant eigenperturbations show singularities. This invalidates both the $\varepsilon-$ and the $1/N-$ expansions. We also show how the Bardeen-Moshe-Bander line of tetracritical FPs at $N = \infty$ and $d = d_{up}$ can be understood from a finite-N analysis.

References

[1] S. Yabunaka and B. Delamotte, arXiv:2301.01021

From fluid dynamics to RG flow studies of phase transitions

J. Braun[1] and N. Zorbach[1]

[1]*Institut für Kernphysik, Technische Universität Darmstadt, Darmstadt, Germany*

We employ a numerical method borrowed from fluid dynamics to solve functional renormalization group flow equations for systems with multiple competing order parameters. We demonstrate the application of our approach with the aid of zero-dimensional quantum field theories which allow us to mimic specific situations also encountered in higher-dimensional theories. Our results suggest that this novel approach indeed represents a promising tool for investigations of spontaneous symmetry breaking and phase transitions in the theory of the strong interaction.