Yukawa International Molecule Workshop / EMMI Program

Renormalization Group Approach from Ultra Cold Atoms to the Hot QGP

ABSTRACT

ANDRONIC, Anton

Hadron production at chemical freeze-out and the QCD phase diagram from high-energy nucleus-nucleus collisions

We investigate the production of hadrons in high-energy nucleus-nucleus collisions within the framework of the thermal (or statistical hadronization) model. We discuss the power and the limitations of the model and how the fits to experimental data are performed. The relevance of the results for the phase diagram of QCD is discussed. We address the light-quark hadrons as well as charmonium, which, within the statistical model, can be identified as a powerful observable for the phase boundary.

BERGES, Juergen

Universality far from Equilibrium

DELAMOTTE, Bertrand

Non-perturbative renormalization analysis of the Kardar-Parisi-Zhang equation

FLÖRCHINGER, Stefan

Turbulent fluctuations in heavy ion collisions

For large Reynolds number (which is inverse to viscosity), fluids are known to develop turbulence. Therefore, the phenomenological evidence for a small viscosity suggests that the hydrodynamical description of heavy ion collisions may have a turbulent regime. Assuming that averaged velocities are described by Bjorkens model, we investigate local fluctuations around it. These perturbations are governed by non-linear equations and we characterize classes of qualitatively different evolution in terms of Reynolds numbers. Perturbations at different rapidities are found to decouple quickly, and the local evolution becomes effectively two-dimensional. The resulting Navier-Stokes equation of non-relativistic form (obtained after suitable coordinate transformations) can be discussed within the theory of Kolmogorov and Kraichnan. In particular, unlike three-dimensional turbulent flow, two-dimensional viscous fluid dynamics can show the interesting phenomenon of inverse cascading of energy into large scale structures. We speculate on possible phenomenological implications of these findings.

GRAHL, Martin

Study of the two-flavor linear sigma model in presence of the axial anomaly with the Functional Renormalization Group

The $SU(2)_A \times U(2)_V$-symmetric chiral linear sigma model in presence of the axial anomaly is studied in the local potential approximation of the Functional Renormalization Group. The RG flow is studied in a truncation which reproduces recent results for the $U(2)_A \times U(2)_V$-symmetric model in the limit of vanishing axial anomaly strength, $c = 0$. We search for the conjectured $O(4)$ fixed point in presence of anomaly, $c \neq 0$, and analyze its stability properties.

HARADA, Koji

A Wilsonian view on the nuclear effective field theory

We explain how a Wilsonian renormalization group analysis of the nuclear effective field theory systematically determines the power counting on the basis of the scaling dimensions of operators near the (nontrivial) fixed point. We emphasize that, when pions are included, the separation of the one-pion-exchange potential into its short-distance and long-distance parts is essential, since their scaling properties are different in the S-waves.

HEBELER, Kai

New Applications of Renormalization Group Methods in Nuclear Physics

Renewed interest in the physics of nuclei is stimulated by experiments at rare isotope facilities, which open the way to new regions of exotic nuclei, and by astrophysical observations and simulations of neutron stars and supernovae, which require controlled constraints on the equation of state of nucleonic matter. The use of Renormalization Group methods to lower the characteristic resolution of inter-nucleon interactions is opening new avenues for calculations of low-energy nuclear structure and reactions. I will give an overview over recent developments and discuss various results for the nuclear equation of state and the consequences for the structure of neutron stars, short-range correlations and the role of many-body forces in nuclear systems.

IGARASHI, Yuji

Realization of symmetries and reduction of the Polchinski flow equations in the ERG

We describe realization of symmetries which are naively incompatible with the regularization scheme in the ERG approach. The Ward-Takahashi identities for such symmetries are derived for the Wilson effective action using a functional method. We also discuss a suitable truncation of the Wilson action which makes it possible to reduce the Polchinski flow equation to its 1PI part, the Wetterich equation.

IPP, Andreas

Scalar theory pressure beyond the local potential approximation

Strict perturbation theory of a scalar theory at finite temperature exhibits the same poor convergence properties as QCD or QED, already at moderately large couplings. It is therefore an ideal test bed to implement improved convergence schemes like improved calculations using the Non-Perturbative Renormalization Group (NPRG).

In this talk I want to present results beyond the already successful Local Potential Approximation (LPA). We apply an improved scheme that has been developed by Blaizot, Mendez-Galain, and Wschebor (BMW). This scheme permits a good determination of the momentum dependence of the n-point functions at zero temperature. Applied to finite temperature, one can expect this method to capture accurately the contributions to the thermodynamical functions of thermal fluctuations from various momentum ranges. This scheme involves also non trivial momentum dependent self-energies. We find that results obtained with this new scheme are not too different from those of the LPA. This suggests that the LPA may already capture the main contribution to the exact pressure. This agreement persists up to the largest couplings, where strict perturbation theory fails miserably. This may also hint to the validity of the quasiparticle picture of such a system.

ITOU, Etsuko

Infrared fixed point for many flavor SU(N) gauge theory

SU(N) gauge theories with various number of fermions and their representations have a non-trivial fixed point in IR region. The theory in such a conformal window shows both an asymptotically freedom and a conformal property in IR region. The motivation to studying the IR behavior of such theories, is not only to distinguishing IR properties of gauge theory, but also phenomenologically important since such theories are potential candidates to explain the origin of electro-weak symmetry breaking beyond the standard model.

I would like to report some recent results for the nonperturbative running coupling and the measurement of the anomalous dimension of composite operators around the fixed point using the lattice simulation.

ITOH, Katsumi

Anomalies in the ERG Approach

The antifield formalism adapted in the exact renormalization group is found to be useful for describing a system with some symmetry, especially the gauge symmetry. In the formalism, the vanishing of the quantum master operator implies the presence of a symmetry. The QM operator satisfies a simple algebraic relation that will be shown to be related to the Wess-Zumino condition for anomalies. We also explain how an anomaly contributes to the QM operator.

JOCHIM, Selim

Few-body physics with ultracold fermions

KLEIN, Bertram

Chiral symmetry breaking and finite-volume effects

Chiral symmetry breaking is - in addition to confinement - the phenomenon that most strongly determines the properties QCD ground state and influences the QCD phase transition at finite temperature and chemical potential.

Since the spontaneous breaking of chiral symmetry gives rise to Nambu-Goldstone bosons, which in turn lead to long-range correlations, the associated phenomena are very sensitive to finite-volume effects. This is important for lattice simulations of QCD in a finite-volume box and influences the phase transition. The finite volume can also be a tool to probe the system for additional information.

We have used the functional RG to investigate such phenomena in the framework of models for chiral symmetry breaking in QCD. The FRG is uniquely suited to these investigations since it accounts for the relevant long-range fluctuation and the critical behavior over a wide range of scales. I will give an overview over the application to different phenomena in this context.

KONDO, Kei-Ichi

Understanding the entanglement between confinement and chiral-symmetry-breaking from QCD

We discuss a possible first-principle derivation of a low-energy effective model of quantum chromodynamics (QCD), which enables one to understand the entanglement between confinement and chiral-symmetry-breaking. We have some implications for improving Polyakov-loop extended Nambu-Jona-Lasinio (PNJL) models. Moreover, we consider how magnetic monopoles contribute to confinement and chiral-symmetry breaking. The basic ingredients are a reformulation of QCD based on new variables, non-Abelian Stokes theorems for the Wilson and Polyakov loops, and the flow equation of the Wetterich type in the Wilsonian renormalization group.

KOPIETZ, Peter

Non-equlilibrium time evolution of bosons from the function renornmalization group

We develop a functional renormalization group approach to obtain the time evolution of the momentum distribution function of interacting bosons out of equilibrium. Using an external out-scattering rate as flow parameter, we derive formally exact renormalization group flow equations for the non-equilibrium self-energies in the Keldysh basis. A simple perturbative truncation of these flow equations leads to an approximate solution of the quantum Boltzmann equation which does not suffer from secular terms and gives accurate results even for long times. We demonstrate this explicitly within a simple exactly solvable toy model describing a quartic oscillator with off-diagonal pairing terms.

References:

T. Kloss and P. Kopietz, Phys. Rev. **B83**, 205118 (2011).

KUNIHIRO, Teiji

RG derivation of relativistic hydrodynamic equations as the infrared dynamics of Boltzmann equation

MITTER, Mario

Aspects of two- and three-flavor chiral phase transitions

The two- and three-flavor chiral phase transition is investigated within a non-perturbative functional renormalization group approach at non-vanishing temperature and quark chemical potential. The temperature dependence of an axial symmetry violating 't Hooft interaction and the consequences are discussed for a two-flavor theory. The influence of the strange quark on the chiral phase transition and on the critical endpoint in the phase diagram are explored.

MUKAIYAMA, Takashi

Universal Thermodynamics of a Unitary Fermi gas

Due to the tunability of the interaction and the stable feature of the ultracold fermionic gases near Feshbach resonances, a degenerate two- component fermionic atom system makes an ideal testing ground for many- body physics. Especially at the unitarity limit where the inter-atomic scattering length diverges and the effective range of interaction is negligible, the scattering length, which is a material-specific interaction parameter, drops out of the description of the energy of the system. This gives rise to universality: the only relevant energy scale left in the system is the Fermi energy. According to this universal hypothesis, all the thermodynamic quantities have a simple and unified form of the function of Fermi energy and temperature normalized by Fermi temperature. However, a complete set of the universal thermodynamic functions has not been determined experimentally so far. In the talk, we present the experimental result of the determination of universal thermodynamic functions at the unitarity limit under the assumption of local density approximation. Using the equation of state and the equation of force balance of a unitary gas in a trap, we are able to determine the internal energy as a function of density and reduced temperature. Once the universal function for the internal energy is obtained, all the other universal functions such as the Helmholtz free energy, chemical potential and entropy can be derived through thermodynamic relations. We also determine all of the thermodynamic quantities at the condensation critical temperature and those values are in good agreement with recent theoretical predictions. The obtained universal functions are crucial for quantitative test of theories for a unitary Fermi gas.

NOWAK, Boris

Nonthermal fixed points in turbulent Bose gases

Far from equilibrium dynamics of Bose gases is analyzed in two and three spatial dimensions. For such systems, universal power-law distributions i.e. nonthermal fixed points, previously found within a nonperturbative quantum-field theoretic approach, are shown to be related to defect turbulence. In the case of dilute ultracold bosons, the nonthermal fixed point is explained from the statistics of superfluid vortices. Characteristic tails in the velocity statistics of vortices are found, which were recently used to experimentally verify a distinction between classical and quantum turbulence. In the case of relativistic bosons, new aspects of reheating after cosmological inflation are presented. Domains of negative and positive charge overdensities separated by thin walls similar to topological defects correspond to the nonthermal fixed point.

PIETRONI, Massimo

Coarse-graining and resummation of cosmological perturbations

SAUERESSIG, Frank

Asymptotically Safe Gravity From Euclidean to Lorentzian Signature

The gravitational asymptotic safety program strives for a consistent and predictive quantum theory of gravity based on a non-trivial ultraviolet fixed point of the renormalization group flow. We investigate this scenario by employing a novel functional renormalization group equation which takes the causal structure of space-time into account and connects the RG flows for Euclidean and Lorentzian signature by a Wick-rotation. Remarkably, the structure of the new equation closely resembles the one encountered when studying quantum field theory at finite temperature. Within the Einstein-Hilbert approximation, the β-functions of both signatures exhibit ultraviolet fixed points in agreement with asymptotic safety. Surprisingly, the two fixed points have strikingly similar characteristics, suggesting that Euclidean and Lorentzian quantum gravity belong to the same universality class at high energies.

SCHAEFER, Bernd-Jochen

With the FRG towards the QCD phase diagram

SCHMIDT, Richard

Renormalization group flow of spectral functions for ultracold quantum gases

A light impurity in a Fermi sea undergoes a transition from polaron to molecule for increasing interaction. We develop a new computational functional RG method to compute the spectral functions of the polaron and molecule in a unified framework with full self-energy feedback. We discuss the energy spectra, decay widths, and the quasi-particle weight of the attractive and repulsive polaron as well as the molecule across the transition.

We finally propose an experimental procedure to measure the repulsive branch using rf spectroscopy and calculate the corresponding spectra.

SCHERER, Michael

Finite-size and Particle-number Eects in an Ultracold Fermi Gas at Unitarity

SKOKOV, Vladimir

Probing QCD phase diagram with fluctuations of conserved charges

In this talk, I review some properties of the QCD phase diagram and discuss what we can learn about it from studies of fluctuations of the conserved charges in experiments with heavy ions. I show the relevance of net-baryon number fluctuations for the analysis of freeze-out and critical conditions in heavy-ion collisions at LHC and RHIC. The properties of fluctuations of the electric and net-baryon charges in the vicinity of the chiral crossover transition are discussed within effective chiral models. The calculation includes non-perturbative dynamics implemented within the functional renormalization group approach. Finally, I present a comparison of the recent experimental data on the probabilities of the net-proton number with hadron resonance gas model results.

SONODA, Hidenori

Universality of ERG formalism, revisited

Following an old work of Latorre and Morris, I would like to reexamine the universality of critical phenomena as described by the ERG formalism.

TARJUS, Gilles

Nonperturbative functional RG for disordered systems: the case of the random-field Ising model

Quenched disorder induces an extrinsic inhomogeneity in otherwise translationally invariant pure systems. As a result, the equilibrium and out-of-equilibrium physics of disordered systems may be influenced by rare collective events and by the proliferation of ?metastable states?. Our objective is to develop a theory describing the long-distance physics of such systems through a nonperturbative functional renormalization group (NP-FRG) method and our first focus is the equilibrium behavior of the random-field Ising model. We formulate the NP-FRG for the critical behavior of the latter in a superfield formalism, which enables us to follow the underlying supersymmetry and its spontaneous breaking along the flow. Breaking is shown to occur below a critical dimension and leads to a breakdown of the so-called 'dimensional reduction' property.

TERAO, Haruhiko

Non-perturbative beta functions and scaling laws in QCD with many quark flavors

It has been known that QCD with sufficiently many flavors becomes scale invariant at the IR region and the scale invariance is lost as the flavor number is reduced. We will evaluate the non-perturbative gauge beta function by using the Exact Renormalization Group equations and show that merger of the IR fixed point and the UV fixed point occurs at the transition point. We will examine the scaling law for the dynamical scale by using the non-perturbative beta function and compare it with the Miransky scaling. We will also show some results on the hyperscaling laws of the chiral order parameters with respect to a bare fermion mass.

TEZUKA, Masaki

One-dimensional Fermi gases: Density-matrix renormaliza-

tion group study of ground state properties and dynamics

In cold atom systems, the wide controllability of the physical parameters with the choice of the trapped atoms and the external fields have made it possible to experimentally investigate various concepts in quantum many-body physics. The atom-atom interaction strength, the potential shape each atom species feels in the space, and the densities of the atom species can be almost independently manipulated.

The density-matrix renormalization group (DMRG) method allows numerically exact study of the ground state properties of one-dimensional lattice systems of interacting atoms. The time evolution of the system under a time-dependent Hamiltonian or after a sudden change of the Hamiltonian can be studied with high accuracy. We applied DMRG to two types of systems of interacting one-dimensional two-species Fermi gases: the population-imbalanced system in a harmonic trap and the population-balanced system in an optical lattice with the site potential modified by a second, incommensurate lattice.

The possibility of Fermi condensate with non-zero pair momentum, the Fulde-Ferrell-Larkin-Ovchinnikov (FFLO, or LOFF) state, has been discussed both in the field of condensed matter physics and nuclear physics for a long time. We demonstrate that in a harmonically trapped one-dimensional Fermi gas the pair correlation shows a periodic sign change, consistent with the Larkin-Ovchinnikov type (quasi-)condensation [1, 2].

Studying the superfluid–insulator transition due to disorder has also been an interesting issue. The disorder strength λ at the insulating transition point depends on the atom-atom interaction [3]. Time evolution can be used to detect superfluidity. We have adopted the time-dependent DMRG method to study the real-time dynamics [4] of the two-component fermions after the shape of the trapping potential is modified while the quasiperiodic potential is kept on. We report on how the dynamics depends on λ and the interaction.

References:

[1] M. Tezuka and M. Ueda, Phys. Rev. Lett. **100**, 110403 (2008).

[2] M. Tezuka and M. Ueda, New J. Phys. **12**, 055029 (2010).

[3] M. Tezuka and A. M. García-García, Phys. Rev. A **82**, 043613 (2010).

[4] A. M. García-García and M. Tezuka, in preparation.

XU, Nu

High-Energy Nuclear Collisions and the QCD Phase Structure

One of the most exciting goals for the field of the high-energy nuclear collisions is to understand the phase structure of matter with partonic degrees of freedom especially the transition from hadronic phase to partonic phase. It is believed that the QCD phase dominates the evolution briefly during the early time of the Universe. In this talk, after reviewing basic concepts regarding strong interactions, I will discuss the recent progresses in the field [1-4]. The focus will be given to those measurements that lead to the understanding of the strongly interacting matter created in high-energy nuclear collisions at RHIC.

References:

[1] PHENIX Experiment at RHIC: http://www.phenix.bnl.gov/

[2] STAR Experiment at RHIC: http://www.star.bnl.gov/

[3] J. Adams, et al., STAR Collaboration, Nucl. Phys. **A757**, 102 (2005).

[4] K. Adcox, et al., PHENIX Collaboration, Nucl. Phys. **A757**, 184 (2005).