TT 2: Focus Session: Recent Developments in Computational Many Body Physics (joint session TT/DY)

This focus session provides an overview of recent achievements and new directions in the domain of computational many body physics. Numerical simulations provide invaluable insights in fermion quantum criticality, many body localization as well as in coupled fermion-boson systems. Tensor networks offer immense possibilities to tackle problems in and out of equilibrium. Finally, new directions such as machine learning and quantum computations will greatly impact the field. All these themes and methods will be discussed by the invited speakers.

Organization: Fakher F. Assaad, Universität Würzburg; Reinhard Noack, Philipps-Universität Marburg

Time: Monday 9:30–12:45 Location: H 0104

Invited Talk TT 2.1 Mon 9:30 H 0104
Revealing Fermionic Quantum Criticality from New Monte Carlo Techniques — •Zi Yang Meng — Institute of Physics, Chinese Academy of Sciences, Beijing 100190, China

In this talk, I will present recent developments in the numerical investigations of fermionic quantum criticality in the form of Fermi surfaces coupled to various critical bosonic fluctuations. The thence obtain itinerant quantum critical points reveal rich and fundamental physics that has immediate impact on both theoretical and experimental investigations in the correlated electrons systems such as Cu- and Ir-based superconductors, heavy-fermion systems as well as the interacting topological state of matter and phase transitions. These developments are made possible due to the insightful model design as well as the timely algorithmic developments in the Monte Carlo techniques.

Invited Talk TT 2.2 Mon 10:00 H 0104
Computational Approaches to Many-Body Localization — •David J. Luitz — Physik Department T42, Technische Universität München, Germany

In the past decade, enormous progress has been made in the understanding of the phenomenon of many-body localization, a dynamical phase of matter in strongly disordered interacting quantum systems far from equilibrium. In particular, the understanding of the phase transition from an extended phase at weak disorder to a localized phase at strong disorder relies heavily on state of the art numerical studies. The numerically accessible system sizes have recently been increased substantially by the introduction of advanced exact numerical techniques: Exact sparse diagonalization as well as matrix product state (MPS) techniques permit the calculation of highly excited eigenstates of the system, whereas exact Krylov space time evolution methods and MPS time evolution methods can be used to study the nonequilibrium dynamics in generic many-body systems. I will give a short survey of current exact numerical techniques (cf [1] for a detailed discussion) to study the MBL phase as well as the transition regime and highlight some results obtained by these approaches.

[1] D. J. Luitz, Y. Bar Lev, Annalen der Physik 529, 1600350 (2017)

Invited Talk TT 2.3 Mon 10:30 H 0104
Tensor Network Techniques and Dynamical Systems — Nicola Pancotti[1], Michael Knapp[2], David Huse[3], Mari Carmen Banuls[1], and •Ignacio Cirac[1] — [1]Max-Planck Institut für Quantenoptic, Garching, Germany — [2]Technical University of Munich, Garching, Germany — [3]University of Princeton, Princeton, US

Tensor networks can be used to efficiently describe the equilibrium properties of many-body quantum systems with local interactions. However, they fail to describe their dynamics, at least for long times. In this talk we will present several methods based on tensor networks to extract dynamical properties of one dimensional spin chains. In particular, we will show how one can construct matrix product operators that quasi commute with the system Hamiltonian, and how this is related to the thermalization process.

15 min. break.

Invited Talk TT 2.4 Mon 11:15 H 0104
Digital Quantum Simulation — •Bela Bauer — Station Q, Microsoft Research, Santa Barbara, CA 93106-6105, USA

Recent improvements in the control of quantum systems make it appear feasible to build a quantum computer within a decade. One of the most promising applications for a quantum computer is the simulation of quantum systems that have thus far eluded numerical simulation on conventional supercomputers. In this talk, I will review the relevant models of quantum computation and survey some potential applications for a small quantum computer. I will then focus on the particular case of simulating complex materials. We show that this important and challenging problem can be tackled using a hybrid quantum-classical algorithm that incorporates the power of a small quantum computer into a framework of classical embedding algorithms.

Invited Talk TT 2.5 Mon 11:45 H 0104
Quantum Monte Carlo Simulation of Coupled Fermion-Boson Systems — Manuel Weber, Fakher Assaad, and •Martin Hohenadler — Institut für Theoretische Physik und Astrophysik, Universität Würzburg, Germany

Problems of fermions coupled to bosonic degrees of freedom can be found in a variety of contexts in condensed matter physics. The bosons may represent, for example, quantum lattice, spin, or orbital fluctuations. Numerical simulations of such problems are challenging because of the bosonic Hilbert space, the different time scales for the fermion and boson dynamics, and the absence of efficient sampling methods for the bosons. In this talk, recent advances in quantum Monte Carlo simulations are presented. By integrating out the bosons, the original problem can be reformulated in terms of fermions with a retarded interaction. The latter can be simulated efficiently by continuous-time quantum Monte Carlo methods. Especially in combination with global updates, simulations can be carried out on system sizes currently inaccessible by any other method. Applications to be presented include the problem of competing electron-phonon couplings as well as charge-density-wave transitions in one and two dimensions.

Invited Talk TT 2.6 Mon 12:15 H 0104
Machine Learning Methods for Quantum Many-Body Physics — •Giuseppe Carleo — ETH Zurich, Institute for Theoretical Physics Wolfgang-Pauli-Str. 27 8093 Zurich - Switzerland

Machine-learning-based approaches are being increasingly adopted in a wide variety of domains, and very recently their effectiveness has been demonstrated also for many-body physics [1-4]. In this talk I will present recent applications to quantum physics.

First, I will discuss how a systematic machine learning of the many-body wave-function can be realized. This goal has been achieved in [1], introducing a variational representation of quantum states based on artificial neural networks. In conjunction with Monte Carlo schemes, this representation can be used to study both ground-state and unitary dynamics, with controlled accuracy. Moreover, I will show how a similar representation can be used to perform efficient Quantum State Tomography on highly-entangled states [5], previously inaccessible to state-of-the art tomographic approaches.

I will then briefly discuss, recent developments in quantum information theory, concerning the high representational power of neural-network quantum states.

[1] Carleo, Troyer, Science 355, 602 (2017).
[2] Carrasquilla, Melko, Nature Physics 13, 431 (2017).
[3] Wang, Physical Review B 94, 195105 (2016).
[4] van Nieuwenburg, Liu, Huber, Nature Physics 13, 435 (2017).
[5] Torlai, Mazzola, Carrasquilla, Troyer, Melko, Carleo, arXiv: 1703.05334.