Symposium Extreme Matter: From Cold Atoms to the Quark Gluon Plasma (SYEM)

jointly organized by
the Quantum Optics and Photonics Division (Q),
the Atomic Physics Division (A), and
the Hadronic and Nuclear Physics Division (HK)

Selim Jochim
Physikalisches Institut
Universität Heidelberg
Im Neuenheimer Feld 226
69120 Heidelberg
jochim@uni-heidelberg.de

Jürgen Berges
Institut für Theoretische Physik
Universität Heidelberg
Philosophenweg 16
69120 Heidelberg
berges@thphys.uni-heidelberg.de

Overview of Invited Talks and Sessions

(Lecture rooms: C/gHS and C/HSO)

Invited Talks

SYEM 1.1	Wed	11:00–11:30	C/gHS	**Generation of Structure under Extreme Conditions: Ultracold Atoms meet Heavy-Ion Collissions** — •Jens Braun
SYEM 1.2	Wed	11:30–12:00	C/gHS	**Strongly Interacting Fermi Gases of Atoms and Molecules** — •Martin Zwierlein
SYEM 1.3	Wed	12:00–12:30	C/gHS	**Towards ultracold RbSr ground-state molecules** — •Florian Schreck
SYEM 1.4	Wed	12:30–13:00	C/gHS	**Multiflavor phenomena and synthetic gauge fields in strongly interacting quantum gases** — •Walter Hofstetter

Sessions

SYEM 1.1–1.4	Wed	11:00–13:00	C/gHS	**Symposium Extreme Matter I**
SYEM 2.1–2.4	Wed	14:30–15:30	C/HSO	**Symposium Extreme Matter II**

SYEM 1: Symposium Extreme Matter I

Time: Wednesday 11:00–13:00 Location: C/gHS

Invited Talk SYEM 1.1 Wed 11:00 C/gHS
Generation of Structure under Extreme Conditions: Ultracold Atoms meet Heavy-Ion Collissions — •Jens Braun — Institut für Kernphysik, TU Darmstadt, Germany

The theory of the strong interaction describes the appearance of the fundamental building blocks of matter in the early Universe. This state of matter is currently probed in relativistic heavy-ion collision experiments, where we encounter temperatures much larger than those of any other experiment. As a complement, experiments with fermionic atoms in the nano-Kelvin regime provide a remarkably clean and versatile environment to test our understanding of a broad range of phenomena: from superconductivity and the formation of condensates to the generation of bound states in strongly coupled systems.

What do these systems have in common? As I will explain in this talk, studies of ultracold atomic gases and the theory of the strong interaction are actually similar in many ways, yet a consistent first-principles description of the experimental data remains challenging. I will present an overview of some of the most intriguing open questions on the phase diagrams of the theory of the strong interaction and ultracold gases, and discuss how an exchange of techniques between these fields is helping us to understand collective phenomena and phase transitions in strongly coupled matter in general.

Invited Talk SYEM 1.2 Wed 11:30 C/gHS
Strongly Interacting Fermi Gases of Atoms and Molecules — •Martin Zwierlein — MIT-Harvard Center for Ultracold Atoms, MIT, Cambridge, USA

In recent years, ultracold gases of fermionic atoms have become a new platform for the realization of paradigmatic forms of strongly interacting matter. Feshbach scattering resonances allow to tune the interactions between atoms at will and to realize the crossover from Bose-Einstein condensation of molecules to Bardeen-Cooper-Schrieffer superfluidity of long-range Cooper pairs. On resonance, we encounter the unitary Fermi gas, with universal properties that closely correspond to those of dilute neutron matter in the crust of neutron stars, and to nuclear matter. I will present our recent study of solitonic excitations in this novel superfluid, the creation of planar solitons and the subsequent cascade into vortex rings and solitonic vortices. To induce strong interactions one may also quench the atoms' kinetic energy in optical lattices. Of great interest here is the realization of the Fermi-Hubbard model, believed to hold the key to understanding high-temperature superconductors. We recently realized imaging of fermionic atoms with single-site resolution in optical lattices, an important step towards the direct observation of magnetic order. Finally, strong, long-range dipolar interactions can lead to novel states of fermionic matter such as topological superfluids. We have created chemically stable, strongly dipolar fermionic molecules, opening up prospects for observing a strongly interacting degenerate Fermi gas with dominant dipolar interactions.

Invited Talk SYEM 1.3 Wed 12:00 C/gHS
Towards ultracold RbSr ground-state molecules — •Florian Schreck — Institute of Physics, University of Amsterdam, The Netherlands

RbSr ground-state molecules possess a strong electric dipole moment and an unpaired electron, providing a magnetic moment. Interactions between the molecules can be tuned by electric and magnetic fields, enabling the creation and exploration of a wide range of many-body quantum systems. An exciting possibility is to induce repulsive van der Waals interactions between the molecules, which might enable evaporative cooling to a quantum gas of ground-state molecules. Another prospect is to exploit the long-range electric dipole interaction to engineer lattice-spin models. I will present our progress towards the creation of ultracold RbSr ground-state molecules and give an overview of the opportunities opened by them.

Invited Talk SYEM 1.4 Wed 12:30 C/gHS
Multiflavor phenomena and synthetic gauge fields in strongly interacting quantum gases — •Walter Hofstetter — Goethe-Universität Frankfurt, Germany

Recent years have witnessed dramatic progress in experimental control and refinement of quantum simulations based on ultracold atoms. One major development are synthetic gauge fields, which allow simulating the dynamics of charged particles and topologically nontrivial phases of matter.

Particularly rich physics arises in multiflavor gases, for example earth-alkalines, which allow implementing higher symmetry groups such as SU(N), and where "color" superfluids and exotic magnetic states have been predicted.

Spectroscopy and real-time dynamics have revealed novel collective modes, in particular the Higgs-amplitude mode of strongly correlated bosons.

I will discuss recent theoretical insights along these directions, which have been obtained by non-perturbative approaches such as variational wavefunctions and Dynamical Mean-Field Theory.

SYEM 2: Symposium Extreme Matter II

Time: Wednesday 14:30–15:30 Location: C/HSO

SYEM 2.1 Wed 14:30 C/HSO
The BEC-BCS crossover in a two-dimensional system — •Andre Wenz, Martin Ries, Gerhard Zürn, Mathias Neidig, Luca Bayha, Dhruv Kedar, Puneet Murthy, and Selim Jochim — Physikalisches Institut, Universität Heidelberg

In recent years ultracold fermionic systems have been used to explore the three-dimensional BEC-BCS crossover. This crossover smoothly links bosonic superfluidity of dimers with a fermionic superfluid of Cooper pairs. Between these two limits lies the strongly interacting regime where the interaction parameter diverges and the critical temperature for superfluidity reaches a maximum. By freezing out the dynamics in some of the spatial directions, one can tune the dimensionality of the system and this leads to a qualitative change of the key properties of the system. For example, for 2D systems the phase transition to the bosonic superfluid phase is then expected to be driven by the BKT mechanism which leads to a topological phase transition associated with the pairing of vortices. We experimentally explore the 2D BEC-BCS crossover using a Fermi gas of ultracold lithium-6 atoms. We observe the phase transition to a low temperature phase by investigating the system's pair momentum distribution. On the bosonic side of the crossover, the observed transition temperature and phase coherence is consistent with the theoretical predictions for a BKT-type phase transition. However, where the 2D interaction strength $1/\ln(k_F a_{2D})$ diverges, theoretical prediction become extremely difficult and our measurements offer the first experimental benchmark to challenge and test theoretical models in this complex regime.

SYEM 2.2 Wed 14:45 C/HSO
Lattice gauge tensor networks, and the SU(2) gauge invariant model — •Pietro Silvi — Ulm universität, Ulm, Deutschland

A unified framework to describe lattice gauge theories by means of tensor networks is presented: this framework is efficient as it exploits the high amount of local symmetry content native of these systems describing only the gauge invariant subspace. The gauge symmetry is cast in terms of the quantum link formulation, which es exploited to achieve a substantial speed-up in real and imaginary time evolution, compared to standard tensor network techniques. This technology is then adopted to study an SU(2)-gauge invariant lattice model, and detect its different phases: this research is meant to idntify the analogies to QCD and other high energy field theories in low dimensions.

SYEM 2.3 Wed 15:00 C/HSO
Quark star matter in a SU(3) chiral Quark-Meson model — •Andreas Zacchi — Goethe Universität Frankfurt

The recent detections of the pulsars PSR J1614-2230 and of PSR J0348+0432 gives strong constraints on the parameter range in effective chiral models which describe *compact stars*. We discuss a chiral quark-meson model with a vacuum energy pressure based on a SU(3) linear-σ-model. Bosonic fluctuations are treated within the 2PI formalism. We study the impact of various parameters on the phase transition, the phase diagram and the equation of state for quark star matter. We solve the TOV-equations to check whether pure quark stars with $\gtrsim 2M_{\odot}$ are feasible within the quark meson model.

SYEM 2.4 Wed 15:15 C/HSO

String Breaking in a (1+1)d Quantum Link Model — •Thomas Pichler — Institut für komplexe Quantensysteme, Universität Ulm, Deutschland

The problem of simulating quantum systems is of ongoing interest in material science, information science and fundamental physics. Modern numerical algorithms allow us to tackle large quantum systems and several experimental implementations with atomic or solid state systems have already begun to perform simulations directly with quantum objects. The progress in the field has motivated to propose more possible applications of such quantum simulators. Recently there have been ideas for the simulation of gauge theories as known from high energy physics on an atomic quantum simulator. In this context we investigate possible applications of such simulators by numerically implementing the proposed gauge theories in tensor network algorithms. Particularly, we look at the (1+1)d quantum link model, also known as reduced Schwinger model, representing quantum electrodynamics in one spatial dimension. This model is a non-perturbative representation of a gauge theory allowing us to study the full out-of-equilibrium dynamics and ground state properties in different parameter regimes. A prominent mechanism expected in quantum chromodynamics is string breaking, which this talk will be focused on.