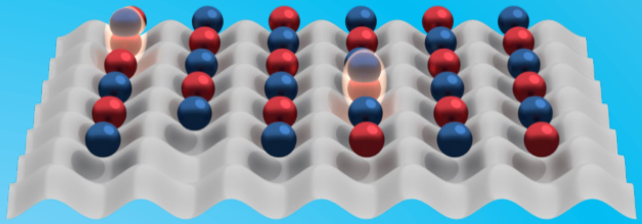
Harvard-Smithsonian Center for Astrophysics
ITAMP
MS-14, B-326
60 Garden Street
Cambridge, MA 02138 USA

QUANTUM PHASES OF FERMIONS IN OPTICAL LATTICES: THE LOW-TEMPERATURE FRONTIER

OCTOBER 8-10 , 2018

Organizers:

Randy Hulet *(Rice University)*
Kaden Hazzard *(Rice University)*
Daniel Greif *(Harvard University)*
Markus Greiner *(Harvard University)*



Sponsored by:

Institute for Theoretical Atomic, Molecular and Optical Physics*

Harvard - Smithsonian Center for Astrophysics
60 Garden St., Cambridge, MA

https://www.cfa.harvard.edu/itamp-event/

Abstracts, Program, Participants, and Guide to ITAMP

*Funded by the National Science Foundation

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Abstracts

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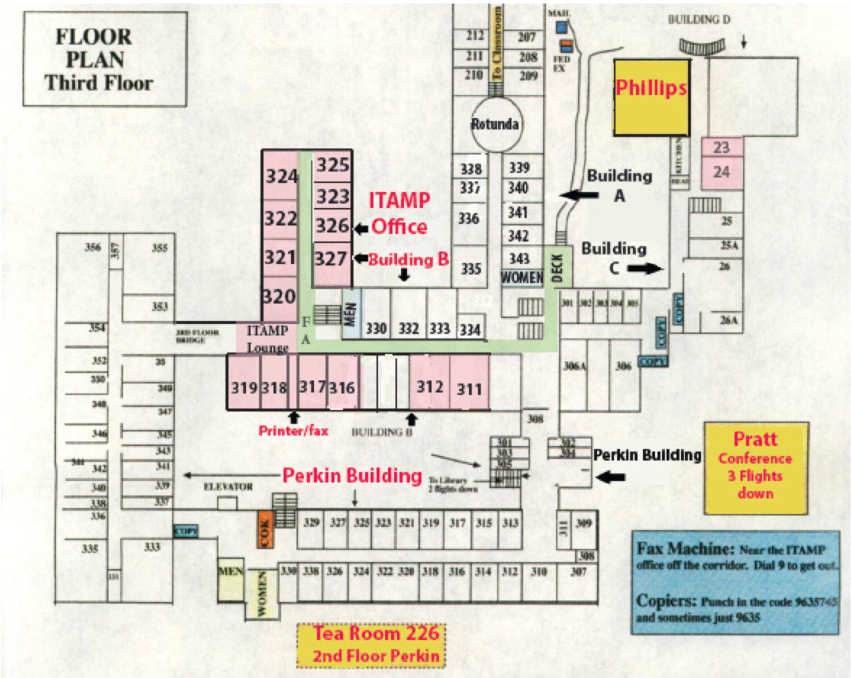
Welcome

ITAMP began life in 1989 at the Harvard-Smithsonian Center for Astrophysics. It is the only theoretical AMO "user facility" in the United States. It hosts workshops (3-days) and topical group meetings (1-4 weeks), and visitors (short- and long-term), has a flagship speaker series, the Joint Atomic Physics colloquia held in Harvard Physics, and a rigorous postdoctoral program. ITAMP workshops are web-cast, when possible, and beginning in 2010, workshop lectures are available on the ITAMP YouTube channel. There are on average 4-5 workshops each year. A Call for Proposal to organize workshops and a list of workshops & topical groups are available at http://itamp.harvard.edu. The postdoctoral program has been a recognized success, placing energetic fellows into junior positions at universities and national labs.

ITAMP thrives in the larger Cambridge-area AMO physics ecosystem, drawing upon the considerable depth and breadth of experimental expertise. The mission of ITAMP continues to be in furthering the cause of theoretical AMO physics by providing resources, centrality of location, and scientific and administrative expertise, to enhance collaborative efforts between theory and experiment, and to be broad in advocating for theoretical AMO.

H. Sadeghpour

ITAMP Floor Plan



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- Description of your visit
- Balance due
- Wire Transfer information (only for international participants with more than 1000 support)

The workshop will bring together theoretical and experimental experts to discuss current challenges fermionic quantum simulation, quantum magnetism, new strategies for creating low-temperature many-body states, quantum thermalization and out-of-equilibrium systems, and microscopic probes and applications to quantum computing and quantum metrology. The experimental platforms will focus on approaches based on neutral fermionic atoms and molecules in optical lattices and optical tweezers.

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Buses to Watertown and Belmont are #71, #73
Harvard Square to Boston: Red Line Train to Park Street Station
Harvard Square to Airport: Red Line Train to South Station. Take the Silver line to Logan Airport. Silver line stops at all terminals. To see the schedule of buses visit http://www.mbta.com/schedules_and_maps/bus/

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House of Chang, 282 Concord Ave.
Trattoria Pulcinella, 147 Huron Ave.
Armanado's Pizza, 163 Huron Ave.
Hi-Rise Bread CO, 208 Concord Ave.
Formaggio Kitchen, 244 Huron Ave

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Simons Coffee House, 1736 Mass. Ave.
Stone Hearth Pizza Co., 1782 Mass. Ave.
Super Fusion, 1759 Mass. Ave.
Cambridge Common, 1667 Mass Ave.
Lizard Lounge, 1667 Mass. Ave.

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Welcome to ITAMP

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Computer Support
The Center for Astrophysics has a large computer network and there are many options for connectivity. In this section, we describe the easiest ways to get on-line. Jim Babb, B-318, can help with questions about how to get connected and related issues. There is also a Computer Help Desk on the second floor, near Room B-215.

Internet Access
Most wireless devices will connect to the "Harvard Guest" account. This works fine and there is no paperwork involved in getting internet access. Other connections are available, should this not work for you for some reason. Please see Jim Babb if you run into problems.

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Copy Machines are located throughout the building (see map) The access code for copy machines throughout the CfA is 9635.

Telephone System
To call outside the University you must dial 9 before the number. The University prefix three digits are 495 and 496. To dial on campus, you simply need to dial the "5" or "6" and the last four digits. For example, ITAMP Admin office's number is 617-495-9524. You can dial 5-9524 to call internally. The Institute is not permitted to pay for long distance calls.

Annabelle Bohrdt
"New probes of the t-J model in quantum gas microscopes"

Elvia Colella (**uibk**)
"Spontaneous cavity-mediated antiferromagnetism in a two component Fermi gas"

Carlos Sa DeMelo
"Chern number spectrum of ultracold fermions in optical lattices tuned independently by artificial magnetic, Zeeman and spin-orbit fields."

Shimpei Goto (**kindai**)
"Kondo Dynamics in Fermionic Alkaline-Earth Atoms at
Finite Temperatures"

Sebastian Greschner
"Universal Hall Response in Synthetic Dimensions"

Thomas Kohlert
"Exploring the Single-Particle Mobility Edge and Many-Body Localized Phase in a 1D Quasiperiodic Optical Lattice with Ultracold Atoms".

Mark Manfred

Cécile Repellin
"Detecting atomic fractional Chern insulators through circular dichroism"

Giacomo Roati
"Experiments on repulsive Fermi gases"

Piotr Sierant
- "Many-body localization of bosons in optical lattices"
- "Weighted model of level statistics across many-body localization transition"

Daisuke Yamamoto
"Quantum frustrated magnetism with fermions in triangular optical lattices: Theoretical proposal and prediction"

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Quantum Phases of Fermions in Optical Lattices: The Low-Temperature Frontier

October 8-10, 2018

Phillips Auditorium

Monday, October 8

8:00am	Registration, Coffee/Pastries
8:25am	Welcome

Chair: Randy Hulet

8:30am	**Andrew Daley** “Dynamical disentangling and dissipative dynamics with ultracold fermions”
9:10am	**Richard Scalettar** “Quantum Simulation Studies of Charge Patterns in Fermi-Bose Systems”
9:50am	**Coffee Break**
10:20am	**Waseem Bakr** “Probing dynamical properties of Fermi-Hubbard systems with a quantum gas microscope”
11:00am	**Selim Jochim** “Correlations and Entanglement in few-body systems”
11:40am	**Martin Zwierlein** “”
12:30pm	**Lunch/Library**

Chair: Carlos De Melo

2:00pm	**Ehud Altman** “Computing Quantum Thermalization Dynamics”
2:40pm	**Giacomo Roati** “Experiments on repulsive Fermi gases”
3:20pm	**Coffee Break**
3:50pm	**Jun Ye** “Emergence of multi-body interactions in a fermionic lattice clock”
4:30pm	**Yvan Castin** “Challenges in the physics of collective modes of superfluid Fermi gases”

Martin Zwierlein

Emergence of multi-body interactions in a fermionic lattice clock

Jun Ye
JILA, NIST and University of Colorado

The interplay of spin-orbit coupled fermions and their s-wave and p-wave interactions gives rise to interesting many-body dynamics in a one-dimensional Sr optical lattice clock. The interactions induce the precession of a collective magnetization, and spin locking emerge from the competition between the spin exchange interaction and SOC-induced spin dephasing.

In a separate effort, we use precision clock spectroscopy in a 3D optical lattice to create arrays of isolated few-body fermionic systems to directly reveal the onset of both elastic and inelastic multibody interactions. The clock transition frequency shifts nonlinearly for atom numbers ranging from 1 to 5, regardless of the choice of nuclear spin states, reflecting the SU(N)-symmetric elastic multi-body mechanism. The study of inelastic multi-body effects provides a clear probe to the short-range few-body physics free from systematic effects encountered in a bulk gas.

Tuesday, October 9

8:00am	Coffee/Pastries

Chair: Hossein Sadeghpour

8:30am	**Brian DeMarco** “Doublon Relaxation Dynamics across Mott and Anderson Transitions in a Fermi Lattice Gas”
9:10am	**Ana Maria Rey** “Collective Spin Dynamics of Weakly Interacting Fermions”
9:50am	**Coffee Break**
10:20am	**Christian Gross** “From incommensurate magnetism to magnetic polarons”
11:00am	**Fabian Grusdt** “New microscopic approaches to the Fermi-Hubbard model - geometric strings & mesons”
11:45am	**Lunch/Library**

Chair: Daniel Creif

1:30pm	**C. Chiu** “String patterns in the doped Hubbard model”
2:10pm	**Simon Fölling** “Two-orbital systems of fermionic Ytterbium”
2:50pm	**Coffee Break**
3:20pm	**Yoshiro Takahash** “Quantum magnetism of ytterbium Fermi gases in an optical lattice”
4:00pm	**Francesca Ferlaino** “Fermi Gases of Dipolar Flavor”
4:45pm	**Poster Session** (Rotunda)

Wednesday, October 10

8:00am	Coffee/Pastries

Chair: TBD

8:30am	**Tin-Lun (Jason) Ho** “Signature of spin, charge, and pairing correlation in fermions in optical lattices from thermodynamic and density measurements”

9:10am	**Eric Mueller** “Quantum dimer models emerging from large-spin ultracold atoms in optical lattices”
9:50am	**Coffee Break**
10:20am	**Tilman Esslinger** “”
11:00am	**Päivi Törmä** “Quantum geometry and superfluidity in lattices”
11:45am	**Lunch/Library**

Chair: Kaden Hazzard

1:45pm	**Nikolai Prokof’ev** “Diagrammatic Monte Carlo results for the 2D Fermi-Hubbard model”
2:25pm	**Antoine Georges** “Matter and Entropy Transport in Cold Atomic Gases”
3:05pm	**Workshop Summary**
3:35pm	Walk to Physics Department
4:30pm	**ITAMP joint Quantum Sceinces Colloquium** **Pablo Jarillo-Herrero** (MIT)

Quantum geometry and superfluidity in lattices

S. Peotta[1], L. Liang[1], A. Julku[1], T.I. Vanhala[1], M. Tovmasyan[2], S.D. Huber[2], K-E. Huhtinen[1], M. Tylukti[1], P. Kumar[1], A. Harju[1], T. Siro[1], D.- H. Kim[3], and **P. Törmä** [1]

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Fermions in flat energy bands are predicted to reach non-zero pairing gaps at high temperatures. Superfluidity, however, has been an open question in flat bands since the usual group velocity is zero. We provide a general expression for the superfluid weight of a multiband superconductor [1-4]. In addition to the conventional part, we identify a geometric contribution to the superfluid weight. This contribution can be non-zero even in a flat band, provided that the band has non-zero Berry curvature, which is guaranteed by a non-zero Chern number. Intriguingly, we find that the superfluid density is connected to the quantum geometric tensor and quantum metric. Thus, even a flat band can carry finite supercurrent, provided that it has a non-trivial quantum geometry. We show [5] that pre-formed pairs dominate the flat band transport even at temperatures above the critical temperature for superconductivity, opening the door for understanding the normal state properties of interacting flat band systems. Existence of a flat band also leads to novel type of FFLO pairing with deformed density [6], and to non-Fermi liquid normal state in the Lieb lattice [7]. We also study the square lattice Hubbard model by dynamical mean-field theory and show coexistence of stripe and d-wave orders [8].

References

[1] S. Peotta, P. Törmä, Nature Communications 6, 8944 (2015) [2] A. Julku, S. Peotta, T.I. Vanhala, D.-H. Kim, P. Törmä, Phys. Rev. Lett. 117, 045303 (2016); L. Liang, T.I. Vanhala, S. Peotta, T. Siro, A. Harju, P. Törmä, Phys. Rev. B 95, 024515 (2017); L. Liang, S. Peotta, A. Harju, P. Törmä, Phys. Rev. B 96, 064511 (2017) [3] M. Tovmasyan, S. Peotta, L. Liang, P. Törmä, S.D. Huber,

https://arxiv.org/abs/1805.04529 (2018) [4] K-E. Huhtinen, M. Tylutki, P. Kumar, T.I. Vanhala, S. Peotta, P. Törmä, Phys.

Rev. B 97, 214503 (2018) [5] P. Kumar, T.I. Vanhala, P. Törmä, Phys. Rev. B 96, 245127 (2017) [6] T.I. Vanhala, P. Törmä, Phys. Rev. B 97, 075112 (2018)

Quantum magnetism of ytterbium Fermi gases in an optical lattice

Yoshiro Takahashi
Department of Physics, Graduate School of Science, Kyoto University, Japan

There has been increasing interest for quantum simulation of Fermi-Hubbard model using two-electron fermionic atoms due to the unique possibilities[1]. In this talk, I will report our recent study on quantum magnetism using ultracold Fermi gases of ytterbium (Yb) atoms in an optical lattice.

A high spin symmetry of SU(N=2I+1) of nuclear spin I is one of the unique properties of Fermi gases of two-electron atoms, which enables us to utilize an enhanced Pomeranchuk cooling effect and study novel quantum magnetism. In our recent study, we successfully observe the formation of nearest-neighbor antiferromagnetic spin correlations of a ^{173}Yb (I=5/2) Fermi gas with SU(N≤6) symmetry in various geometries of optical lattices[2] by exploiting the method developed for potassium atoms[3]. For the SU(4) and SU(6) cases we successfully observe the antiferromagnetic spin correlation for 1D , 2D , and 3D optical lattices at our lowest temperature. In the case of dimerized lattice, by comparing the behaviors of SU(2) and SU(4) fermions, we confirm that the Pomeranchuk cooling effect, previously demonstrated for the formation of a Mott insulating state, also works for inducing spin correlation within the dimer. This work is an important step towards the realization of various novel SU(N) quantum magnetism.

The existence of the long-lived metastable states of two-electron atoms also offers unique possibilities. In particular, the two-orbital system of the $^3P_0$ and the ground $^1S_0$ states is a candidate for the quantum simulation of a Kondo effect [4]. Different from the previously studied atomic species which show ferromagnetic spin-exchange interaction, we recently investigate a Fermi gas of ^{171}Yb atoms and a systematic clock transition spectroscopy at various magnetic field reveals that the spin-exchange interaction is antiferromagnetic, which is useful in the quantum simulation of a Kondo effect.

I will discuss the details of the above-mentioned works.

This work has been done in collaboration with S. Taie, Y. Takasu, H. Ozawa, T. Yagami, N. Nishizawa, K. Sakuma, Y. Kuno, K. Ono, Y. Amano, and J. Kobayashi.

References

1. M. A. Cazalilla and A. M. Rey, Rep. Prog. Phys.77, 124401 (2014).
2. H. Ozawa, S. Taie, Y. Takasu, and Y. Takahashi, arXiv:1801.05962
3. D. Greif, T. Uehlinger, G. Jotzu, L. Tarruell, and T. Esslinger, Science 340, 1307 (2013).
4. A. V. Gorshkov et al., Nat. Phys. 6, 289 (2010).

Computing Quantum Thermalization Dynamics

Ehud Altman
University of California, Berkeley

Computing the dynamics of strongly interacting quantum systems presents a fundamental challenge due to the growth of entanglement entropy in time. I will describe two new approaches to overcome this obstruction. The first scheme employs the time dependent variational principle with matrix product states and is able to capture chaotic dynamics and emergent hydrodynamic transport in certain one dimensional systems. The second approach is based on a truncation scheme of operator dynamics that makes use of new insights on operator growth and its relation to emergent dissipation. In addition to capturing the emergent hydrodynamics and diffusion in non-integrable quantum systems this scheme can diagnose and detect hidden slow operators and capture the non diffusive dynamics in certain integrable models.

Probing dynamical properties of Fermi-Hubbard systems with a quantum gas microscope

Waseem Bakr
Princeton University

The normal state of high-temperature superconductors exhibits anomalous transport and spectral properties that are poorly understood. Cold atoms in optical lattices have been used to realize the celebrated Fermi-Hubbard model, widely believed to capture the essential physics of these materials. The recent development of fermionic quantum gas microscopes has enabled studying Hubbard systems with single-site resolution. Most studies have focused on probing equal-time spin and density correlations. In this talk, I will report on using a microscope to probe response functions associated with unequal-time correlations relevant for understanding the pseudogap and strange metal regimes of Fermi-Hubbard systems. First, I will describe the development of a technique to measure microscopic diffusion, and hence resistivity, in doped Mott insulators. We have found that this resistivity exhibits a linear dependence on temperature and violates the Mott-Ioffe-Regel limit, two signatures of strange metallic behavior. Next, I will report on the development of angle-resolved photoemission spectroscopy (ARPES) for Hubbard systems and its application to studying pseudogap physics in an attractive Hubbard system across the BEC-BCS crossover, setting the stage for future studies of the pseudogap regime in repulsive Hubbard systems.

Quantum Simulation Studies of Charge Patterns in Fermi-Bose Systems

Richard Scalettar
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The Holstein Model describes the interaction between fermions and a collection of local (dispersionless) phonon modes, and has intimate connections to the attractive Hubbard Hamiltonian. In the dilute limit, the phonon degrees of freedom dress the fermions, giving rise to polaron and bipolaron formation. At higher densities, the phonons mediate collective superconducting (SC) and charge density wave (CDW) phases. Quantum Monte Carlo (QMC) simulations have considered both these limits, but have not yet focused on the physics of more general phonon spectra.

Here we report QMC studies of the role of phonon dispersion on SC and CDW order in such models. We quantify the effect of finite phonon bandwidth and curvature on the critical temperature $\$T_{cdw}$ for CDW order, and also uncover several novel features of diagonal long range order in the phase diagram, including a competition between charge patterns at momenta $\mathbf{q=(\pi,\pi)}$and $\mathbf{q=(0,\pi)}$ which lends insight into the relationship between Fermi surface nesting and the wavevector at which charge order occurs. We also demonstrate SC order at half-filling in situations where nonzero bandwidth sufficiently suppresses $T_{cdw.}$ We conclude the presentation by discussing a new, Langevin-based, algorithm which allows efficient simulations of a range of models appropriate to Bose-Fermi mixtures of atomic gases.

"Phonon dispersion and the competition between pairing and charge order", N.C. Costa, T. Blommel. W.-T. Chiu, G.G. Batrouni, and R.T. Scalettar, Phys. Rev. Lett. 120, 187003 (2018).

Collective Spin Dynamics of Weakly Interacting Fermions:

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Ultracold atoms, benefiting from long-lived coherence and controllable interactions, offer an ideal system to shed light on the organizing principles and universal behaviors of out-of-equilibrium quantum systems. Here, I will discuss our observation of a dynamical phase transition from a state with ferromagnetic order to a demagnetized state upon changing the interaction coupling below a critical value in a quantum simulator of the collective Heisenberg model with an inhomogeneous axial field [1] .The spin model was engineered using weakly interacting ultra-cold fermionic potassium atoms frozen in their single-particle energy modes, which serve as lattice sites. The spins were encoded in two hyperfine states and coupled by s-wave contact interactions which become long range in mode space. We explored the dynamical phase diagram by tuning both interactions and field inhomogeneity and found excellent agreement with theoretical predictions based on a pure spin model. We also demonstrated that time evolution can be effectively reversed, and magnetic order recovered by dynamically inverting the sign of only those parameters that describe the spin model instead of the full microscopic Hamiltonian. The identification of a parameter window where long-range spin lattice models are simulated without a real-space lattice opens a route for the generation of collective and highly coherent quantum states in large fermionic ensembles and a path for their application to enhanced metrology and advanced technologies.

References:

[1] Scott Smale, Peiru He, Ben A. Olsen, Kenneth G. Jackson, Haille Sharum, Stefan Trotzky, Jamir Marino, Ana Maria Rey, Joseph H. Thywissen, Observation of a Dynamical Phase Transition in the Collective Heisenberg Model, arXiv:1806.11044 (2018)

Challenges in the physics of collective modes of superfluid Fermi gases

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We will try to show that, in the spatially homogeneous case now accessible in the laboratory, the collective modes of superfluid (spin 1/2 unpolarized) Fermi gases pose some simple and fundamental questions that have not yet been solved theoretically and experimentally:

- when the dispersion relation of the acoustic excitation branch is concave (as is the case in the BCS limit), what is precisely the phonon damping rate in the gas due to the sound non-linearity? The three-phonon mechanism of Beliaev-Landau is forbidden by the conservation of energy and momentum. A four-phonon mechanism was proposed by Landau and Khalatnikov in 1949, but our recent calculations contradict the results obtained by these authors on the damping rate.
- phonons are also damped by coupling to BCS atom-Cooper-pair breaking excitations, always present at nonzero temperature. What exactly is the corresponding damping rate? Our calculations of phonon-BCSon coupling, generalizing those of Landau and Khalatnikov on phonon-roton coupling in liquid helium 4, show that terms have been neglected or even omitted by these authors.
- the Fermi superfluids of positive chemical potential have, in their pair-breaking continuum, a collective excitation branch predicted by Littlewood and Varma in 1982 in the weakly interacting regime, which is also called (may be abusively) Higgs branch. Our calculations, which extend to the regime of strong interaction, predict however a different dispersion relation; in particular, the damping rate of the continuum collective modes at zero temperature would tend to zero quadratically rather than linearly with the wave number.

References :

[1] H. Kurkjian, Y. Castin, A. Sinatra, "Landau-Khalatnikov phonon damping in strongly interacting Fermi gases", EPL 116, 40002 (2016).
[2] H. Kurkjian, Y. Castin, A. Sinatra, "Three-phonon and four-phonon interaction processes in a pair-condensed Fermi gas", Annalen der Physik 529, 1600352 (2017).
[3] Y. Castin, A. Sinatra, H. Kurkjian, "Landau phonon-roton theory revisited for superfluid He 4 and Fermi gases", Phys. Rev. Lett. 119, 260402 (2017).
[4] H. Kurkjian, S.N. Klimin, J. Tempere, Y. Castin, "Collective branch in the continuum of BCS superconductors and superfluid Fermi gases", arXiv:1805.02462 (2018).

String patterns in the doped Hubbard model

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Quantum simulation is rapidly emerging as a powerful technique to understand the physics of strongly correlated materials. Quantum gas microscopy of ultracold fermionic atoms in an optical lattice is perfectly suited to study the Fermi-Hubbard model, a model widely believed to capture the physics of high-temperature superconductivity. We realize a Fermi-Hubbard antiferromagnet and investigate the interplay between hole motion and spin order through doping the antiferromagnet. In addition to using conventional observables such as the spin correlation function and the staggered magnetization, we explore the potential for new pattern-based microscopic observables for quantum simulation of strongly correlated materials.

Diagrammatic Monte Carlo results for the 2D Fermi-Hubbard model

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UMass. Amherst

It is commonly believed that in unbiased quantum Monte Carlo approaches to generic fermionic many-body problems the infamous sign-problem implies prohibitively large computational times for obtaining thermodynamic-limit quantities with ever increasing accuracy. This perception is a rumor. We prove that for convergent diagrammatic series the computational time increases only polynomially with the inverse error on thermodynamic-limit quantities. I will discuss the status of current simulations for the 2D Fermi-Hubbard model, the ground-state phase diagram of superfluid states, the onset of strong magnetic correlations, and the possible phase separation near half-filling.

Quantum dimer models emerging from large-spin ultracold atoms in optical lattices

Erich Mueller
Cornell University

Quantum dimer models -- which describe the dynamics of close-packed hard-core dimers on a lattice -- have been hugely influential in developing paradigms for how constraints lead to novel physics, including topological order and fractionalization. Despite their importance, there are relatively few experimental realizations of dimer models. I will explain how atoms in an optical lattice, in the presence of an off-resonant photoassociation laser, can be described by a quantum dimer model. Our numerical studies of this model reveal dimer crystal and resonating plaquette phases. Photoassociation can be used to directly measure the spatial pattern of dimer correlations.

Reference:

Bhuvanesh Sundar, Todd C. Rutkowski, Erich J. Mueller, Michael J. Lawler, Quantum dimer models emerging from large-spin ultracold bosons, arXiv:1702.05514

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Dynamical disentangling and dissipative dynamics with ultracold fermions

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The extraordinary progress in experiments with ultracold fermionic atoms over the past few years has opened new opportunities to explore out of equilibrium dynamics in setups with low temperatures, and access to lattice systems with site-resolved imaging and control. In addition to time-dependent control over coherent dynamics, these systems also allow us to explore controlled dissipative many-body dynamics. Separations of energy scales allow us to write microscopic models for light scattering and particle loss, and to explore the consequences of these processes in strongly interacting regimes. I will discuss some of our recent theoretical work exploring new possibilities with dissipative dynamics in these systems, especially the use of bilayer systems for dynamical disentangling and cooling of ultracold fermions, and transport dynamics of fermionic atoms in the presence of dissipation.

Doublon Relaxation Dynamics across Mott and Anderson Transitions in a Fermi Lattice Gas

Brian DeMarco
University of Illinois

The behavior of excitations in the disordered Hubbard model is a key problem that underpins our understanding of metal-insulator transitions. I will discuss recent measurements of doublon decay times for an ultracold Fermi gas trapped in a disordered cubic optical lattice. In these experiments, we use an interaction quench to create an excited state composed of excess doublons. The decay of doublons is measured during subsequent equilibration. We observe three distinct regimes that span over two order of magnitude in relaxation time as the disorder is tuned at fixed interaction strength. Slow relaxation is measured in a clean lattice, in which decay is suppressed by the Mott gap. Above a critical disorder threshold, the relaxation abruptly becomes much faster, and the decay time approaches the single-particle tunneling time. For larger disorder, the relaxation time slows beyond the clean limit without any sign of saturation. Lattice modulation spectroscopy confirms that these different dynamical regimes are accompanied by the collapse of the Mott peak and emergence of a spectrally uniform state. I will explain how these measurements are consistent with predicted Mott insulator—correlated metal—Anderson-Mott insulator transitions for the ground state. We vary the interaction and disorder strengths interdependently to map out a dynamical phase diagram for the strongly correlated regime.

Experiments on repulsive Fermi gases: what we have learnt about

Giacomo Roati
Cnr-Ino And Lens

We present our experimental studies on the out-of-equilibrium dynamics of ultracold Fermi gases of 6Li atoms. In a first experiment, we study the spin dynamics of strongly repulsive Fermi gases initialized into an artificial ferromagnetic state [1]. For sufficiently high values of repulsive interactions and sufficiently low temperatures, we observe a softening of the spin dipole mode and a time-window during which spin diffusion is zeroed. In a second experiment, we employ radio-frequency spectroscopy to selectively quench the gas onto the repulsive branch near a Feshbach resonance [2]. We probe the emergence of both anti-correlations in the upper branch and pairing correlations in a time-resolved fashion. We measure the spectral response of atoms and pairs, retrieving the many-body dynamics in real time. Our work provides fundamental insights into the fate of a repulsive Fermi gas and it clarifies previous observations.

[1] G. Valtolina et al., Nature Physics 13, 704 (2017)
[2] A. Amico et al., arXiv:1807.10208 (2018)

Correlations and Entanglement in few-body systems

Selim Jochim
University Heidelberg, Germany

Using spin resolved imaging of individual atoms in free space we measure both the position and momentum distributions of a deterministically prepared few body system. These measurements allow us to determine correlations and entanglement of the motional degree of freedom and will be an important tool in our queest to enhance our understanding of the properties of complex many body systems where strong correlations between the particles are a key ingredient.

Tilman Esslinger

Fermi Gases of Dipolar Flavor

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Recently, dipolar quantum gases are proving themselves as a powerful resource to address fundamental questions and realize novel interaction paradigms in few- and many-body quantum physics. Following the footsteps of beautiful experiments on Fermi gases with contact-interacting particles, we conduct studies on ultracold dipolar fermionic, using a highly-magnetic atomic species, Erbium. The potential of dipolar gases relies on the long-range and anisotropic character of the inter-particles interaction.

Remarkably, when endowing ultracold fermions with a dipolar character, interactions among identical particles survives to ultralow temperatures. In this regime, we observe the impact of dipole-dipole interaction at both the few-body level, as elastic dipolar scattering enables efficient evaporative cooling, and at the many-body level with the deformation of the Fermi surface. Moving to large interaction regimes, we realize a strongly interacting Fermi gas using a mixture of Er spin states and an inter-spin magnetic Feshbach resonance, and we characterize the system for future studies on the BEC-to-BCS crossover. Finally, dipolar fermions allows for exchange interactions and spin excitation in a lattice-confined setting.

This talk will provide an overview from the Innsbruck prospective of some fascinating phenomena with dipolar Fermi gases (Er) and with the newly created dipolar mixtures (Er-Er and **Er-Dy).**

Signature of spin, charge, and pairing correlation in fermions in optical lattices from thermodynamic and density measurements

Tin-Lun (Jason) Ho
The Ohio State University

I shall discuss the signatures of pairing correlations of fermions in optical lattices in equation of state measurements; as well as the pronounced features on spin and particle density due to motions of spinors and holons in optical lattice ladders.

New microscopic approaches to the Fermi-Hubbard model — geometric strings & mesons

Fabian Grusdt
Harvard University

The complex interplay of spin and charge degrees of freedom is at the heart of high-Tc superconductivity and the complex many-body phases found in its vicinity in strongly correlated materials. Here we show on a microscopic level that this interplay gives rise to short-range hidden string order, which can be directly detected using quantum gas microscopy. We propose a new paradigm to describe the properties of individual holes moving in a spin-background with pronounced anti-ferromagnetic correlations, where the lattice geometry is dynamically modified along so-called geometric strings. Direct numerical and experimental evidence of such geometric strings will be presented. Our new insights suggest that strongly correlated quantum materials and high-energy particle physics are closely connected, and pave the way for developing a detailed microscopic understanding of the doped Fermi-Hubbard model in the future, both theoretically and experimentally.

Two-orbital systems of fermionic Ytterbium

Simon Fölling
LMU, Munich

Fermionic ytterbium as an alkaline-earth-like atom features an SU(N)-symmetric ground state and a metastable “clock” state, which opens up the possibility of exploring interacting two-orbital many-body systems. The resulting interorbital spin-exchange interaction leads to nuclear spin coupling dynamics between the orbitals, as well as to a novel type of Feshbach resonance in the specific case of ytterbium 173, due to an unusually shallow bound state.

This recently observed orbital Feshbach resonance allows to tune the interaction strength magnetically. In our experiment, we probe the effect of orbital interactions both in bulk, where we observe this for example in polaron formation, as well as in lattices. In particular, state-dependent optical lattices allow for the implementation of Kondo-like models, which rely on the presence of spin-exchanging interaction.

For ytterbium 173, resonant two-particle interactions can even allow for tuning the strong spin-exchange inside a 3D optical lattice without a magnetic field, in analogy to confinement-induced resonances. In the case of ytterbium 171, we observe a spin-exchange term of non-resonant type, with opposite sign to Yb-173. This makes the bare exchange coupling term antiferromagnetic, which in combination allows for a wide range of coupling parameters to be realized.

Matter and Entropy Transport in Cold Atomic Gases

Antoine Georges
AG, College de France (Paris)
and Flatiron Institute (Simons Foundation, New York)

From incommensurate magnetism to magnetic polarons

Christian Gross
Max Planck Institute of Quantum Optics, Munich

The Hubbard model offers an intriguing playground to explore strongly correlated many-body systems. Much of its complexity arises from the interplay of spin and charge degrees of freedom. Here we report on the experimental study of one- and two-dimensional synthetic Hubbard systems implemented on the optical lattice platform. We discuss the recent observation of incommensurate magnetism in one dimension and the imaging of magnetic polarons in two dimensions. Due to our spin and charge resolved imaging technique, our observations are independent of any presumed model. Future extensions of these experiments may allow one to study the interaction of polarons as a precursor to collective many body physics in the Hubbard model.