SFB/TRANSREGIO 49

FRANKFURT-KAISERSLAUTERN-MAINZ

CONDENSED MATTER SYSTEMS WITH VARIABLE MANY-BODY INTERACTIONS

INTERNATIONAL SCHOOL 2017

REAL AND SYNTHETIC MAGNETISM

JOHANN WOLFGANG GOETHE UNIVERSITÄT FRANKFURT AM MAIN

TECHNISCHE UNIVERSITÄT KAISERSLAUTERN

JOHANNES GUTENBERG UNIVERSITÄT MAINZ

SPIN+X SFB/TRR 173

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COLLEGE FOR THE ADVANCEMENT OF POSTGRADUATE EDUCATION

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Introduction

International School on Real and Synthetic Magnetism

sponsored by

Collaborative Research Center SFB/TR49

The International School will provide a concise overview about recent progress in fundamental spin effects in the realm of condensed matter physics and how they can be realized in artificial systems. The pedagogical talks are provided by both experimental and theoretical physicists of international reputation.

Within the framework of the Collaborative Research Center SFB/TR49 **Condensed Matter Systems with Variable Many-Body Interactions**, which is funded since 2007 by the German Research Foundation (DFG), the collective behavior of interacting many-body systems is investigated on a broad phenomenological context. The topics embrace cooperative phenomena such as the Mott metal-insulator transition, superconducting/superfluid phases with strong interactions or Bose-Einstein condensation under various and sometimes extreme conditions. Besides the properties of the ground state, excitations and exchange processes, also containing dynamical aspects of correlations and coherence, are investigated in the SFB/TR49.

Further information about the Collaborative Research Center SFB/TR49 is available at its homepage

http://www.tr49.de

College for the Advancement of Postgraduate Education in the SFB/TR49

The researchers of the SFB/TR49 strive for two principle goals: The production of international first-class research results and the education of qualified experts and scientists of many-body interactions in condensed matter physics, both of which are equally important responsibilities towards society. It is an universally accepted truth that these two areas, research and postgraduate education, go hand in hand. Success in one area also requires excellence in the other and vice versa.

The College for the Advancement of Postgraduate Education is an integrated graduate school with the primary intention of improving and furthering the education of young researchers affiliated with the research projects of the Transregio. The College keeps high academic standards and strives for an optimal graduation time of three years for PhD candidates. To this end, the College will provide training opportunities, guidance, and a pleasant networking environment in order to assist the research progress of doctoral students towards graduation without delays. The College assists members in acquiring a variety of other skills that are expected from doctoral candidates on their way to become a self-reliant researcher, who not only excels in science, but is also ready to fill the position of a leading, responsible and independent scientist as demanded in all parts of society. The College offers many customized and transregional training opportunities, such as workshops, seminars, soft skill courses, lecture series, exchanges, books, excursions, information services, and - last but not least - personal career development and guidance.

Further information about the College for the Advancement of Postgraduate Education is available at its homepage

http://lucky.physik.uni-kl.de/~tr49/mgk

International School on Real and Synthetic Magnetism

Building on the success of various educational activities within the College for the Advancement of Postgraduate Studies, we organize for the fourth time an international school which is geared towards specific topics in methods and research for students. The summer school is open for international registration and the lectures will be given by invited experts. It covers many research fields of the SFB/TR49 and is, therefore, of central importance.

The international school in Tutzing covers magnetic phenomena, which occur in either real or synthetic systems. In particular, concrete examples within the realm of frustrated magnets, magnon Bose-Einstein condensates, ultracold quantum gases in traps or optical lattices as well as ion traps are treated in detail. Although all these systems are physically quite different, their respective magnetic phenomena reveal certain similarities which will be worked out. Furthermore, the school aims at providing an overview over both the theoretical and the experimental probing of the respective magnetic properties.

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WLAN

consult the reception

Program

Monday, March 27

Until 14:00	Arrival at venue
14:00-15:00	*Coffee and Registration*
15:00-15.15	Judith Stumptner (Evangelische Akademie Tutzing): *Welcome*
15:15-15:30	Sebastian Eggert (Kaiserslautern): *Opening*
15:30-16:45	Sergej Demokritov (Münster): *Bose-Einstein Condensation of Magnons at Room Temperature – Creation, Spatio-Temporal Properties and Possible Superfluidity*
16:45-17:00	Discussion
17:00-18:15	Christof Wunderlich (Siegen): *Spin-Phonon and Spin-Spin Interactions with Trapped Atomic Ions – Part I*
18:15-18:30	Discussion
18:30-20:00	*Dinner*
20:00	Poster Session I and Socializing

Tuesday, March 28

07:30-08:30	*Breakfast*
08:30-09:45	Christof Wunderlich (Siegen): *Spin-Phonon and Spin-Spin Interactions with Trapped Atomic Ions – Part II*
09:45-10:00	Discussion
10:00-10:30	*Coffee Break*

10:30-11:45	Rembert Duine (Utrecht):
	Spintronics and Magnon Bose-Einstein Condensation – Part I
11:45-12:00	Discussion
12:00-12:30	Stefan Süllow (Braunschweig):
	Frustrated Quantum Magnets:
	Real Materials Versus Magnetic Models – Part I
12:30-14:00	*Lunch*
14:00-14:45	Stefan Süllow (Braunschweig):
	Frustrated Quantum Magnets:
	Real Materials Versus Magnetic Models – Part I
14:45-15:00	Discussion
15:00-15:30	*Coffee Break*
15:30-16:45	Selim Jochim (Heidelberg):
	The BEC-BCS Crossover:
	Tuning Strong Correlations in a Dilute Gase – Part I
16:45-17:00	Discussion
17:00-18:15	Carlos Sa de Melo (Atlanta):
	Quantum Phase Transitions and the BCS-BEC Evolution
	with Population Imbalance – Part I
18:15-18:30	Discussion
18:30-20:00	*Dinner*
20:00	Poster Session II and Socializing

Wednesday, March 29

07:30-08:30	*Breakfast*
08:30-09:45	Rembert Duine (Utrecht): *Spintronics and Magnon Bose-Einstein Condensation – Part II*
09:45-10:00	Discussion
10:00-10:30	*Coffee and Lunch Package*
10:30-18:30	Excursion to Neuschwanstein Castle
18:30-20:00	*Dinner*
20:00-21:15	Stefan Süllow (Braunschweig): *Frustrated Quantum Magnets:* *Real Materials Versus Magnetic Models – Part II*
21:15-21:30	Discussion

Thursday, March 30

07:30-08:30	*Breakfast*
08:30-09:45	Selim Jochim (Heidelberg): *The BEC-BCS Crossover:* *Tuning Strong Correlations in a Dilute Gase – Part II*
09:45-10:00	Discussion
10:00-10:30	*Coffee Break*
10:30-11:45	Carlos Sa de Melo (Atlanta): *Quantum Phase Transitions and the BCS-BEC Evolution* *with Population Imbalance – Part II*
11:45-12:00	Discussion
12:00-13:30	*Lunch*
13:30	Departure from venue

Abstracts of Lectures

Bose-Einstein Condensation of Magnons at Room Temperature: Creation, Spatio-Temporal Properties and Possible Superfluidity

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Magnons are the quanta of waves of spin precession in magnetically ordered media. In thermal equilibrium, they can be considered as a gas of quasiparticles obeying the Bose-Einstein statistics with zero chemical potential and a temperature dependent density. We will discuss the room-temperature kinetics and thermodynamics of the magnon gas in yttrium iron garnet films driven by a microwave pumping and investigated by means of the Brillouin light scattering (BLS) spectroscopy. We show that the thermalization of the driven magnon gas results in a quasi-equilibrium state, which is described by the Bose-Einstein statistics with a non-zero chemical potential, the latter being dependent on the pumping power. For high enough pumping powers Bose-Einstein condensation (BEC) of magnons can be experimentally achieved at room temperature. Spatio-temporal kinetics of the BEC-condensate will be discussed in detail. Among others interference of two condensates, persistent quantized vortices, and propagating waves of the condensate density will be addressed. Finally, our recent experiments on moving condensates will be discussed.

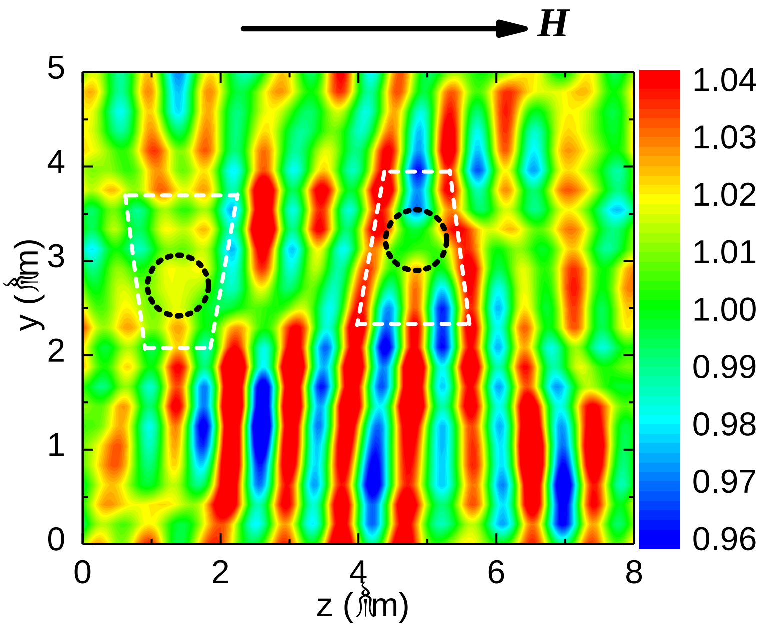

Figure 1: Measured two-dimensional spatial map of the BLS intensity proportional to the magnon condensate density. Note a periodic structure resulting from interference between two condensates. Dashed circles show the positions of topological defects in the standing-wave pattern corresponding to persistent quantized vortices existing in the condensate.

Spintronics and Magnon Bose-Einstein Condensation

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Spintronics is the science and technology of electric control over spin currents in solid-state-based devices [1]. Recent advances have demonstrated a coupling between electronic spin currents in non-magnetic metals and magnons in magnetic insulators (see figure). The coupling is due to so-called spin transfer and spin pumping at interfaces between the normal metals and magnetic insulators. In these lectures, we aim at giving a pedagogical introduction to these concepts and developments. We will also discuss the prospects they raise for electric control of quasi-equilibrium magnon Bose-Einstein condensates and spin superfluidity.

[1] R.A. Duine, A. Brataas, S.A. Bender, and Y. Tserkovnyak, arXiv:1505.01329

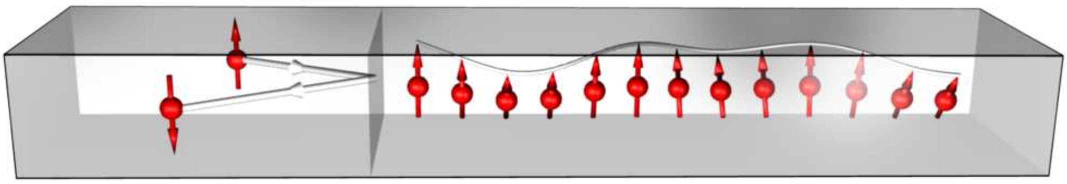

Figure 1: Schematic coupling between electronic spin currents in non-magnetic metals and magnons in magnetic insulators.

The BEC-BCS Crossover: Tuning Strong Correlations in a Dilute Gas

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Using ultracold gases, researchers have been able to realize states of matter that had been predicted long before in a very beautiful manner. Some of the most striking examples are the Bose-Einstein condensate, or the Mott-insulating state in a lattice.

Ultracold gases have furthermore contributed tremendously to understanding states of matter that had been under intense investigation for decades. A particularly extreme example is the continuous crossover from a Bose-Einstein condensate of molecules (BEC) to a Cooper-paired state of weakly attractive fermionic atoms (BCS): The atomic interactions can be tuned by simply applying a magnetic field using so-called Feshbach resonances in such a controlled way that initially the attraction between atoms is large enough such that molecules are formed from two fermionic atoms that are then bosonic in nature. As the attraction between these molecules is reduced, the binding becomes weaker, and the size of the molecules grows until their size becomes comparable with the interparticle spacing. Reducing the attraction further, the bound state between two atoms vanishes completely, and the system is paired only in a many-body context, a behavior that is well known from BCS theory. In fact, this crossover regime has been under intense theoretical investigation for decades, in particular as very high critical temperatures can be found ($> 0.15\, T_{\mathrm{F}}$).

The very high critical temperatures observed in this so-called crossover regime motivated further studies bringing these systems closer to real solid-state materials, with the vision to get inspiration for a better understanding of high-T_c materials. During the past years we have therefore investigated this crossover in reduced dimensions by shaping the trap confining the atoms in such a way that motional degrees of freedom are frozen out. This leads to the observation of the so-called Berezinskii-Kosterlitz-Thouless phase, a topological phase with quasi-long range order, and also to the identification of a regime in which pairing occurs at unexpectedly large temperatures.

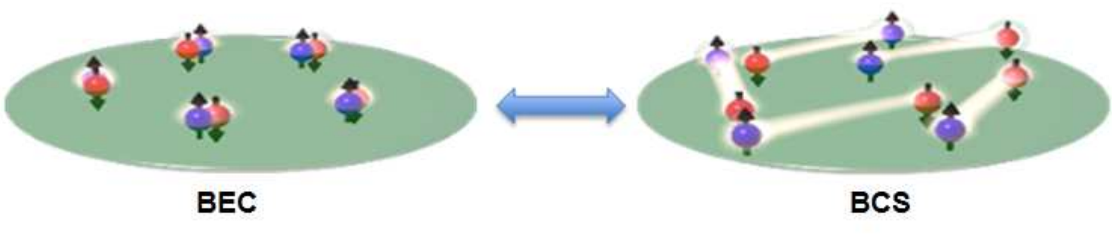

Figure 1: Schematic illustration of the BEC-BCS crossover.

Quantum Phase Transitions and the BCS-BEC Evolution with Population Imbalance

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In these two lectures I will describe a couple of examples of exotic quantum phase transitions that emerge in the context of ultra-cold atoms, when Fermi mixtures are subject to population (spin) imbalance. I will focus on the emergence of superfluid phases of these mixtures with changing attractive interactions.

In the first lecture, I will introduce the problem of the evolution from BCS to BEC superfluids as interactions are tuned for population (spin) balanced system of fermions of equal mass, and show that a simple crossover between weak and strong coupling superfluid phases occurs. However, when population (spin) imbalance is present, new superfluid phases with topological structure emerge, and quantum phase transitions take place as interactions are tuned. Prototypical examples are equal-mass Fermi systems, such as ^{6}Li-^{6}Li or ^{40}K-^{40}K mixtures, where connections to known condensed matter systems involving electrons can be made.

In the second lecture, I will discuss the more exotic problem of a mixture of fermions with unequal masses, where interactions between them, as well as the populations of each type of fermion can be tuned. In this case, the prototypical example is the Fermi mixture ^{6}Li-^{40}K, which does not have an easy connection to known condensed matter systems. I will discuss the quantum phases that emerge and show that the mass differences lead to an asymmetric phase diagram along the axis of population imbalance. I will conclude that the mass anisotropy can stabilize uniform superfluid phases when light fermions are in excess.

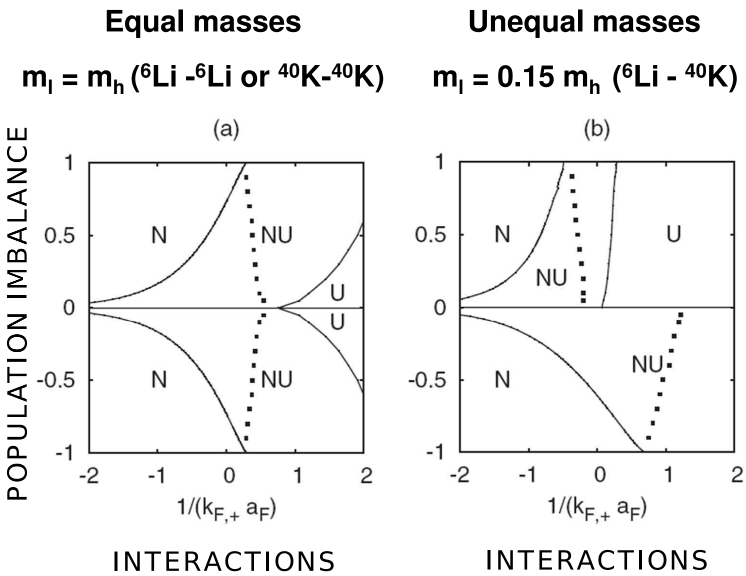

Figure 1: Zero temperature phase diagrams of population (spin) imbalance versus interactions (scattering length) for equal and unequal mass Fermi mixtures. The normal phase is denoted by N, the uniform superfluid phase is denoted by U, and non-uniform phases are denoted by NU. In (a) the masses of fermions are the same, while in (b) the mixture has lighter fermions with mass m_l and heavier fermions with mass m_h. Examples of such mixtures are ^{6}Li-^{6}Li or ^{40}K-^{40}K for equal masses and ^{6}Li-^{40}K for unequal masses.

Frustrated Quantum Magnets: Real Materials Versus Magnetic Models

Stefan Süllow
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Modern research on frustrated quantum magnets is advanced by the close interplay of experimental and theoretical studies. On the experimental side, most importantly, it requires the availability of materials to provide test cases for probing the different magnetic models. While identifying suitable materials, the first step is always a thorough sample characterization, here using analytical concepts stemming from chemistry, metallurgy and condensed matter physics. Subsequently, more specialized experimental tools can be used in order to verify specific theoretical predictions. In the lecture, an overview is given about these concepts and tools, as well as the pitfalls encountered, by discussing selected case studies on frustrated quantum magnets.

Spin-Phonon and Spin-Spin Interactions with Trapped Atomic Ions

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Trapped atomic ions are a particularly well characterized quantum system, whose properties are under detailed control of an experimenter. Ion Coulomb crystals can be employed to simulate static and dynamic properties of other interacting quantum systems, for example, for investigating magnetism. In this tutorial I introduce essential elements of the physics of trapped atomic ions when they are used for such quantum simulations. It will be outlined how appropriately chosen internal states of individual atomic ions confined in a Paul trap provide spin degrees of freedom, and how these spins can be initialized and measured individually. Adding a state-dependent force to a Coulomb crystal of trapped ions for instance, by applying a magnetic field gradient or by light-induced forces such that ionic states serving as effective spins acquire a differential shift in energy leads to long-range spin-spin coupling between pairs of ions. The range, strength and exact form of the coupling can be controlled by adjusting the trapping potential, by the additional forces that are applied to the Coulomb crystal, and by state preparation. After introducing essential elements of the physics of trapped ions as outlined above, I will give an overview of recent quantum simulation experiments with spin-spin coupled trapped atomic ions.

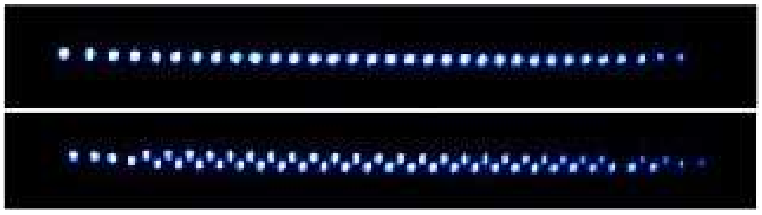

Figure 1: Exemplary images of different ion Coulomb crystals: Resonance fluorescence near 369 nm of individual Yb^+ ions confined in a linear Paul trap is imaged onto a spatially resolving photodetector.

List of Posters

Abasalt Bahrami (Mainz):
Microtrap for Hybrid Rb-Yb^+ Systems

Martin Bonkhoff (Kaiserslautern):
Interacting Anyons in a One-Dimensional Optical Lattice

Pascal Frey (Kaiserslautern):
Progress in Wavevector-Resolved Brillouin Light Scattering Spectroscopy of Magnon Gases and Condensates

Steffi Hartmann (Frankfurt):
Lattice Effects Accompanying the Colossal Magnetoresistance Effect in $HgCr_2Se_4$

Steve Haupt (Kaiserslautern):
Immersing Single Cs Atoms in a Rb BEC

Kevin Jägering (Kaiserslautern):
Antiferromagnetic Dynamical Spin Structure Factor in Doped Heisenberg Chains

Hamidreza Kazemi (Kaiserslautern):
Electron Transport and Spin Torque Effects in Quasi 1D Domain Walls

Lukas Keller (Frankfurt):
Magnetic Quasi 2D and Real 3D Structures Prepared by Focused Electron Beam Induced Deposition

Alexander Kreil (Kaiserslautern):
Magnon Supercurrents by Thermal Gradients

Polina Matveeva (Kaiserslautern):
Spin-Wave Dynamic and Exchange Interactions in Multiferroic $NdFe_3(BO_3)_4$: Inelastic Neutron Scattering Investigation

Halyna Musiienko-Shmarova (Kaiserslautern):
Direct Observation of Dipolar-Exchange Magnon and Phonon Thermal Spectra in Arbitrary Magnetized Yttrium-Iron-Garnet Films

Benjamin Nagler (Kaiserslautern):
Towards Studies of the BEC-BCS Crossover in a Disordered Environment

Timo Noack (Kaiserslautern):
Electrical Detection of Magnon-Bose-Einstein-Condensates

Lars Postulka (Frankfurt):
Thermodynamic Investigations on Kagome Systems

Pascal Puphal (Frankfurt):
Novel Kagome Systems

Muhammad Sajid (Bonn):
Quantum Hall Physics with Quantum Walks in a Synthetic Magnetic Field

Christian Thurn (Frankfurt):
Thermal Expansion Measurements on $Cs_2CuCl_{4-x}Br_x$ *at Sub-Kelvin Temperatures*

Etienne Wamba (Kaiserslautern):
Exact Mapping Between Different Dynamics of Artificial Condensed Matter Systems

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Notes

time	Monday	time	Tuesday	time	Wednesday	time	Thursday
		until 08:30	Breakfast	until 08:30	Breakfast	until 08:30	Breakfast
		08:30-10:00	**Christof Wunderlich** *Spin-Phonon and Spin-Spin Interactions with Trapped Atomic Ions – Part II*	08:30-10:00	**Rembert Duine** *Spintronics and Magnon Bose-Einstein Condensation – Part II*	08:30-10:00	**Selim Jochim** *The BEC-BCS Crossover: Tuning Strong Correlations in a Dilute Gase – Part II*
		10:00-10:30	Coffee Break	10:00-10:30	Coffee and Lunch Package	10:00-10:30	Coffee Break
		10:30-12:00	**Rembert Duine** *Spintronics and Magnon Bose-Einstein Condensation – Part I*	10:30-18:30	Excursion to Neuschwanstein Castle	10:30-12:00	**Carlos Sa de Melo** *Quantum Phase Transitions and the BCS-BEC Evolution with Population Imbalance – Part II*
until 14:00	Arrival	12:00-12:30 14:00-15:00	**Stefan Süllow** *Frustrated Quantum Magnets: Real Materials Versus Magnetic Models – Part I*			12:00-13:30	Lunch
14:00-15:00	Coffee and Registration	12:30-14:00	Lunch			13:30-	Departure
15:00-15:30	Welcome and Opening	15:00-15:30	Coffee Break				
15:30-17:00	**Sergej Demokritov** *Bose-Einstein Condensation of Magnons at Room Temperature – Creation, Spatio-Temporal Properties and Possible Superfluidity*	15:30-17:00	**Selim Jochim** *The BEC-BCS Crossover: Tuning Strong Correlations in a Dilute Gase – Part I*				
17:00-18:30	**Christof Wunderlich** *Spin-Phonon and Spin-Spin Interactions with Trapped Atomic Ions – Part I*	17:00-18:30	**Carlos Sa de Melo** *Quantum Phase Transitions and the BCS-BEC Evolution with Population Imbalance – Part I*				
18:30-20:00	Dinner	18:30-20:00	Dinner	18:30-20:00	Dinner		
20:00-	Poster Session I	20:00-	Poster Session II	20:00-21:30	**Stefan Süllow** *Frustrated Quantum Magnets: Real Materials Versus Magnetic Models – Part II*		