001  
**Topological defects and phase transitions**  
*Kosterlitz J.M.*  
Brown University, Physics, Providence, United States  

This talk reviews some of the applications of topology and topological defects in phase transitions in two-dimensional systems for which Kosterlitz and Thouless split half the 2016 Physics Nobel Prize. The theoretical predictions and experimental verification in two dimensional superfluids, superconductors and crystals will be reviewed because they provide very convincing quantitative agreement with topological defect theories.

002  
**Topological superfluids**  
*Volovik G.*,\(^1\,^2\)  
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Phases of liquid 3He represent topological matter with exotic defects protected by topology in r-space and nodes in fermionic spectrum protected by p-space topology. Phases of 3He belong to 4 classes.  
(i) Normal 3He and normal metals belong to class with Fermi surfaces. Extension of Fermi surface to flat band opens the route to room-T superconductivity.  
(ii) 3He-A - chiral superfluid with topologically protected Weyl fermions - is analog of Standard Model (SM). Its bosonic modes include effective gauge bosons and gravitons. Analogs of chiral anomaly, chiral magnetic and vortical effects have been experimentally demonstrated. Above Landau critical velocity the type-II Weyl points are formed. Such points are also formed in Weyl semimetal and behind the black hole horizon, which allows us to simulate Hawking radiation in semimetals.  
(iii) In fully gapped 3He-B the p-space topology is similar to r-space topology of skyrmions and protects Majorana fermions on surface. The Nambu rule connecting spectrum of Higgs and fermionic modes in 3He-B, suggests extra Higgs bosons in SM.  
(iv) Polar phase of 3He has Dirac nodal lines and contains 2D flat band of surface Majorana fermions. In semimetals with Dirac lines, the surface flat band is possible source of high-T superconductivity.
15.50-16.50
Congress Hall

003
On the pairing mechanism of unconventional high temperature superconductivity
Xue Q.-K.
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The pairing mechanism of unconventional high Tc superconductivity in cuprates and iron-pnictides has remained as a major problem in condensed matter physics. Both cuprates and iron-pnictides have a layered crystalline structure where charge reservoir layers reside in both sides of superconducting layers that are difficult to be measured directly by most experimental techniques. By using state-of-the-art molecular beam epitaxy (MBE)-scanning tunneling microscopy (STM), we are able to study the gap structures of superconducting copper oxide and FeSe planes by low temperature STM [1, 2]. Our results reveal that the pairing symmetry in two systems is actually isotropic and can be explained in the framework of BCS theory. We propose a model for understanding the complicated phase diagram of unconventional high temperature superconductors.

References:
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Friday, 11 August 2017
14.50-15.20
Congress Hall

004
2D crystalline superconductors with broken inversion symmetry
Saito Y.1, Wakatsuki R.1, Hoshino S.2, Itahashi Y.1, Ideue T.1, Ezawa M.1, Nagaosa N.2, Iwasa Y.1
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Recent advances have developed methods to produce ideal two-dimensional (2D) electron systems, which are highly-crystalline with minimal disorder [1]. Here, we introduce the recent developments of highly-crystalline 2D superconductors and a series of unprecedented physical properties discovered originating from inversion symmetry in these systems. First of all, we highlight the quantum phases, i.e., quantum metallic state [2] and the quantum Griffiths phase [3] in out-of-plane magnetic fields. In addition, we focus two novel phenomena owing to broken inversion symmetry originating from crystal structure in ion-gated MoS2: one is the experimental observation of enhanced in-plane upper critical field up to 52 Tesla by spin-valley locking (Ising superconductivity) [4] and the other is the nonreciprocal superconducting transport, the latter of which is later expected to be universal phenomena in noncentrosymmetric superconductors [5]. This nonreciprocal transport can be regard as intrinsic ratchet effect originating from noncentrosymmetric structure. These series of unprecedented phenomena suggest that highly-crystalline 2D superconductors evidently offer tremendous opportunities to unveil the intrinsic exotic nature of superconductors, leading to a new era of 2D superconductivity.

References:
005
Critical velocity in the presence of surface bound states in superfluid $^3$He-B
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¹University of Waterloo, Physics and Astronomy, West Waterloo, Canada, ²University of Florida, Physics, Gainesville, United States, ³Hong Kong University of Science and Technology, Physics, Hong Kong, China

A microelectromechanical oscillator with a gap of 1.25µm was immersed in superfluid $^3$He-B and cooled below 250µK at various pressures. Mechanical resonances of its shear motion were measured at various levels of driving force. The oscillator enters into a nonlinear regime above a certain threshold velocity. The damping increases rapidly in the nonlinear region and eventually prevents the velocity of the oscillator from increasing beyond the critical velocity which is much lower than the Landau critical velocity. We propose that this peculiar nonlinear behavior stems from the escape of quasiparticles from the surface bound states into the bulk fluid.

References:

006
Imaging Andreev reflection under magnetic field in graphene†
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Harvard University, Department of Physics and School of Engineering and Applied Sciences, Cambridge, United States

Graphene (G) channels with superconducting (S) contacts combine the long mean free path of Dirac fermions with the coherence of Cooper pairs [1,2]. An Andreev reflection allows a normal electron in graphene to bounce off S as a hole (Figs.1a,b), while it transmits a Cooper pair [3]. We use a cooled scanning probe microscope (SPM) to image Andreev reflection in a hBN-G-hBN device (Fig 1c) at 4.2 K with normal (N) and superconducting (S) contacts in a perpendicular magnetic field $B$. Using our SPM, we have previously imaged magnetic focusing of electrons in graphene [4]. Fig 1a illustrates the cyclotron orbit for an electron passing from contact N1 to S, and a hole passing from S to N3; a Cooper pair passes into S. Orbits of electrons and holes are imaged by deflecting their paths with the SPM tip, and displaying the voltage $V_m$ between N3 and N4 as SPM tip is raster scanned above the sample. Fig 1d shows an SPM image of Andreev reflection in the magnetic focusing regime, where the cyclotron diameter equals N1 to S and S to N3 - the blue region shows the cyclotron orbits of electron
from N1 and the holes reflected from S. Using ray tracing simulations, we model the electron and hole orbits associated with Andreev reflection (Fig. 1e), which matches well with the experimental result.

**Figure 1:** (a,b) Schematic showing Andreev reflection at the graphene/superconducting interface. In a perpendicular magnetic field B, an electron entering the graphene from the normal (orange) contact on the follows a cyclotron orbit. When it hits the superconducting contact in the center (green), a hole is emitted owing to Andreev reflection. (c) SEM image of the hBN-graphene-hBN device patterned with four normal (N) gold contacts and a superconducting (S) niobium contact. A current I is passed between from N1 to the superconducting contact S, contacts S and N2 are grounded. The voltage Vn is measured between N3 and N4. (d) SPM image of Andreev reflection under magnetic field in the magnetic focusing regime at 4.2 K – the blue region shows the cyclotron orbit of electrons traveling to the superconducting contact and the holes reflected. (e) Image of Andreev reflection obtained using ray tracing simulations. Both images at B = 0.31T and electron density n = 1.29 x 10^{12} cm^{-2}.

References:
Engineering the coupling of Yu-Shiba-Rusinov states in a chain of magnetic adatoms

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1University of Hamburg, Department of Physics, Hamburg, Germany, 2Uppsala University, Department of Physics and Astronomy, Uppsala, Sweden

Recently, it has been proposed that a chain of magnetic adatoms (MA) hosting a spin-spiral on an s-wave superconductor (SC) may give rise to spinless p-wave pairing in this chain and the emergence of Majorana modes at the ends of the chain [1]. The subsequent investigation of self-assembled ferromagnetic Fe chains on superconducting Pb, featuring strong spin-orbit coupling, triggered enhanced interest in the possible realization of Majorana end modes [2]. However, Yu-Shiba-Rusinov (YSR) states close to the Fermi energy can hinder a doubtless assignment of those modes [3]. Moreover, for realizing quantum circuits for applications, one needs to artificially construct such chains and control the coupling between the MA.

Here, we will present our investigation towards the engineering of the coupling between MA and an underlying SC as well as amongst the MA. The tip of a scanning tunneling microscope has been used as a tool to construct dimers, trimers and chains of Fe atoms on an oxygen reconstructed Ta(001) surface, and the YSR states have been studied by scanning tunneling spectroscopy. Our work demonstrates the possibility of tuning the coupling within the artificially constructed Fe-atom chain and adds an important step towards the controlled realization of Majorana end states.

References:

Vortex non-dynamics and exceeding the Landau speed limit in the polar phase of superfluid 3He

Mäkinen J.T.1, Autti S.1, Eltsov V.B.1, Rysti J.1, Volovik G.E.1,2
1Aalto University, Low Temperature Laboratory, Espoo, Finland, 2Landau Institute for Theoretical Physics, Chernogolovka, Russian Federation

The Fermi surface emerges in superfluids and superconductors in the presence of supercurrent, when the velocity of the superflow exceeds Landau critical velocity.1 The fermionic quasiparticles then occupy the negative energy levels, giving rise to non-zero normal component density even at zero temperature.2 The superflow above the Landau critical velocity remains stable until the density of the non-thermal normal component reaches the total density, or the critical velocity for vortex formation is exceeded.

Here we report observation of the super-Landau supercurrent in the polar phase of superfluid 3He. The Landau critical velocity in the polar phase is zero, like in the A phase,3 since the polar phase is gapless: it contains the Dirac nodal line in the equatorial plane in momentum space.4,5
Using BEC of magnon quasiparticles as a probe we have found that superflow in the polar phase remains stable for velocities up to 0.3 cm/s. Above this velocity vortex lines are formed. The vortices in the polar phase are pinned so strongly that they remain in place for days after the rotation has stopped. We also report an attempt to determine non-thermal part of the normal density from high-accuracy measurements of the Leggett frequency in the NMR experiments.

References:
We employ inelastic neutron scattering (INS) to study the field dependence of spin fluctuations in CeB$_6$. The exciton shows no field splitting in marked contrast to CeCoIn$_5$. Instead, we observe a second field-induced magnon whose energy increases with field. At the ferromagnetic zone center, however, we find only a single mode with a nonmonotonic field dependence. At low fields, it is initially suppressed to zero together with the antiferromagnetic order parameter, but then reappears at higher fields inside the hidden-order phase, following the energy of an electron spin resonance (ESR). This is a unique example of a ferromagnetic resonance in a heavy-fermion metal seen by both ESR and INS consistently over a broad range of magnetic fields.

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Thursday, 10 August 2017
11.50-12.10
Congress Hall

011
Flat Andreev bound states at a dirty surface of a nodal superconductor and odd-frequency Cooper pairs
Asano Y., Ikegaya S.
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The quantization of an observable value in physics is closely related to some of the time to an invariant in mathematics. We focus on the minimum value of the zero-bias differential conductance $G_{\text{min}}$ in a junction consisting of a dirty normal metal and a nodal superconductor preserving time-reversal symmetry. Our analytical results based on the quasiclassical Green function method show that $G_{\text{min}}$ is quantized at $(4e^2/h)N_{\text{ZES}}$ in the limit of strong impurity scatterings in the normal metal at zero temperature [1,2]. The integer $N_{\text{ZES}}$ represents the number of Andreev bound states at zero energy which assist the perfect transmission through the dirty normal metal. An analysis of the chiral symmetry of the Hamiltonian indicates that $N_{\text{ZES}}$ corresponds to the Atiyah-Singer index in mathematics [3]. The perfect transmission of a Cooper pairs is responsible for the fractional Josephson effect in a dirty Josephson junction [4,5] which has been a central issue in Majorana physics.

We have discussed that odd-frequency Cooper pairs play an essential role in such unusual proximity effect. In the presentation, we will demonstrate the stable paramagnetic superconducting states due to odd-frequency pairs in a small nodal superconductor.[6]

References:
The anomalous metallic phase in an atomically thin van der Waals superconductor

de la Barrera S.\textsuperscript{1}, Sinko M.\textsuperscript{1}, Lanes O.\textsuperscript{2}, Liu G.\textsuperscript{2}, Hatridge M.\textsuperscript{2}, Hunt B.\textsuperscript{3}

\textsuperscript{1}Carnegie Mellon University, Pittsburgh, United States, \textsuperscript{2}University of Pittsburgh, Pittsburgh, United States

The zero-temperature limit of a two-dimensional electron system is thought to support only insulating and superconducting states. Experimental studies of thin-film superconductors have verified that a direct transition between the two states is possible by varying disorder or an external magnetic field. Surprisingly, an intermediate metallic phase with finite, saturating resistivity in the presence of a small perpendicular magnetic field has also been observed in a variety of ultrathin superconducting materials. Here, we report the observation of such an anomalous metallic ground state in atomically thin 2H-TaS\textsubscript{2}, a crystalline superconductor which also exhibits Ising symmetry-protection and an unusual trend in its critical temperature. We investigate the low-temperature magnetotransport signatures of this metallic state and discuss a few of the possible underlying mechanisms.

Thursday, 10 August 2017
12.10-12.30
G3

Specific heat and entropy in the second Landau level

Schmidt B.\textsuperscript{1}, Bennaceur K.\textsuperscript{1}, Gervais G.\textsuperscript{1}, Pfeiffer L.\textsuperscript{2}, West K.\textsuperscript{2}

\textsuperscript{1}McGill University, Montreal, Canada, \textsuperscript{2}Princeton University, Princeton, United States

The difficulty of edge-based measurements has led to interest in alternative means of testing whether fractional quantum Hall states, such as $\nu=5/2$, are non-Abelian. In principle, there should be a non-Abelian contribution to the entropy, which would be detectable by measuring thermodynamic quantities such as specific heat \cite{1}. In this talk, we will introduce our technique to measure the specific heat of a 2DEG in absolute units with no contribution of the phonons or other addenda. Working in the Corbino geometry, we measure both the DC thermal conductance to the environment and the thermal relaxation time. Our measured thermal relaxation times are around 1 microsecond at 100 mK, and the magnitude and temperature dependence of the power dissipation suggest cooling via phonon emission. We use a simple thermal RC-circuit model to determine the heat capacity of the electronic system, which is found to follow Arrhenius-like activation behavior. Integration of our results to obtain the entropy at filling factors 5/2 and 7/3 yields good quantitative agreement with previous measurements of entropy via the thermopower \cite{2}. By extending our technique to lower temperatures and exploring the flank of $\nu=5/2$, it may be possible to detect the entropic signature of bulk non-Abelian anyons.

References:

\begin{itemize}
  \item \cite{1} N. R. Cooper and A. Stern, Phys. Rev. Lett. \textbf{102}, 176807 (2009).
  \item \cite{2} W. E. Chickering, J. P. Eisenstein, L. N. Pfeiffer, and K. W. West, Phys. Rev. B \textbf{87}, 075302 (2013).
  \item \cite{3} B. A. Schmidt, K. Bennaceur, S. Gaucher, G. Gervais, L. N. Pfeiffer, K. W. West, arxiv:1605.02344
\end{itemize}

Thursday, 10 August 2017
11.30-11.50
H1
Effect of carbon coating on the superconducting properties of Sn nano-spheres
Shani L., Kumar V.B., Gedanken A., Shapiro I., Shapiro B.Y., Shaulov A., Yeshurun Y.
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Carbon coating is commonly used to protect superconducting nano-particles. In this paper we show that the coating process may cause doping of the superconducting material and thus may affect drastically its properties. Tin spheres of radius ~60 nm and ~700 nm coated with sub-nanometer carbon layers were fabricated, using a sonochemical technique. Samples of both spheres reveal a type-I superconductivity characterized by super-critical fields and an intermediate state manifested by a gradual increase of the magnetization to zero. However, the small and large tin spheres exhibit similar critical fields, \( H_c \), contrary to the expected increase in \( H_c \) in spheres with size smaller than the coherence length (~230 nm). Analysis of the data shows that the relative high degree of carbon doping in the small tin spheres eliminates the expected size-effect on \( H_c \). Simulations, based on the time dependent Ginzburg-Landau equations, imply that the intermediate state in both measured samples consists of only one superconducting domain surrounded by a normal domain, whereas a rich multi-domain structure is predicted for larger Sn spheres.

Momentum space imaging of chiral unconventional superconductors UPt₃ and URu₂Si₂
Thalmeier P., Lambert F., Akbari A., Eremin I.
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Surface tunneling quasiparticle interference (QPI) investigation is able to specify the symmetry of superconducting (SC) gap functions, in particular in heavy fermion compounds where the size of the gap is quite small. This has been successfully demonstrated in CeCoIn₅. UPt₃ is the only known 2-component unconventional SC belonging to a two-dimensional hexagonal E-representation. Existing experiments cannot distinguish between the chiral E₁g, E₂u and E₁u models. Using a finite-slab calculation we show that the QPI images of those gap functions have characteristic differences. In particular for zero bias they show signature of different Weyl arc structure of surface states stemming from the different topological charges of the nodes. This provides a powerful criterion to decide between gap models [1].

In URu₂Si₂ presumably a chiral d-wave singlet SC state exists inside a hidden order (HO) phase.. We show that the QPI pattern contains clues on the HO reconstructed quasiparticle bands and the essential HO property of in-plane rotational symmetry breaking. We also demonstrate that the chiral d-wave SC gap leads to a crossover to a quasi-2D QPI spectrum below \( T_c \) which sharpens the HO features. We give a comparison with existing STM experiments in the HO phase.

References:
Dynamical magnetism in the iron-based ladder compound BaFe2Se3 through multi-probe techniques

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¹Tohoku University, Institute for Materials Research, Sendai, Japan, ²Tohoku University, Department of Physics, Sendai, Japan

Since the discovery, Fe-based superconductivity (SC) has attracted much attention. To gain further insight into the mechanism of SC, investigation of Fe-based compounds over distinct spatial dimensions is important. We have examined magnetism of ladder compounds AFe2X3 (A = Rb, Cs, Ba; X = S, Se) [1,2], and recently found the first SC in BaFe2S3 [3]. As for other parent compounds, this family shows 3D magnetic ordering. However, anomaly at the magnetic transition is not detectable by bulk properties.

For BaFe2Se3, Block-type magnetic structure below TN = 255 K was elucidated by neutron diffraction [1]. However, Moessbauer experiment reports no anomaly at TN, instead hyperfine splitting appears at 235 K. There is a gradual formation of the magnetic ordering on further cooling, and it finally falls into the ordered state at 10 K, consistent with hindered entropy release evidenced by the specific heat [1]. This behavior can be originating from the difference in timescale of the techniques (neutron: 1e-13 sec, Moessbauer: 1e-7 sec). Here we report on magnetic dynamics of BaFe2Se3 through multi-probe techniques including neutrons and muons. Observed magnetic fluctuations over a wide regime of temperatures are inherent to low-dimensionality of the material.

References:

Motion beyond Landau critical velocity in a Fermi superfluid

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We study drag forces on objects that move in a p-wave Fermi superfluid at velocities on the order of the Landau critical velocity v_L. We concentrate on low temperatures where quasiparticle collisions can be neglected. For a point-like impurity we calculate analytically the force, which vanishes at T=0 for v<v_L and starts to increase toward its normal state value for v>v_L. The situation is more complicated for an object larger than the coherence length scale. Firstly, the superfluid flow around the object causes part of the incident ground state quasiparticles to be Andreev reflected, giving only a weak force on the object. Secondly, the flow field is modified by local pair breaking already at object velocities less than v_L. We calculate self-consistently the velocity field using different approximations, and calculate the resulting force on the object. As a technical tool we propose a “macroscopic” diffuse-scattering boundary condition in the superfluid state, where quasiparticles are scattered equally in all allowed directions, consistently with conservation of mass and excitation number.
018
Unconventional superconductivity and quantum criticality in heavy fermions CeIrSi$_3$ and CeRhSi$_3$

Landaeta J.F.$^1$, Subero D.$^1$, Catalá D.$^1$, Taylor S.V.$^1$, Kimura N.$^2$, Settai R.$^3$, Onuki Y.$^4$, Sigrist M.$^5$, Bonalde I.$^1$

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Superconductivity and magnetism are mutually exclusive in most alloys and elements, so it is striking that superconductivity emerges around a magnetic quantum critical point (QCP) in many strongly correlated electron systems (SCES). In the latter case superconductivity is believed to be unconventional and directly influenced by the QCP. However, experimentally unconventional superconductivity has neither been established nor directly been linked to any mechanism of the QCP. To gain insight into these open questions, we developed a measuring system, to study the superconducting order parameter symmetry under pressure using a high-resolution magnetic penetration-depth $\lambda(T)$ probe. Here we report measurements of $\lambda(T)$ in heavy fermions CeIrSi$_3$ and CeRhSi$_3$ up to 3 GPa and 200 mK. Superconductivity in CeIrSi$_3$ shows a change from a line-nodal to an isotropic gap structure when pressure is close but not yet at the QCP. In contrast, CeRhSi$_3$ does not possess an obvious pressure-tuned QCP and the superconducting phase remains for all accessible pressures with a nodal gap. Combining both results suggests that unconventional behaviours may be connected with the coexisting antiferromagnetic order. This study provides a new viewpoint on the interplay of superconductivity and magnetism in SCES.
critical regime and results in nontrivial scaling in Dirac semimetals. However, it is often difficult to drive a system with Dirac points across the massless fermionic critical point. Here, by exploiting screening of local moments under spin-orbit interactions in a Kondo lattice, we show that the Kondo lattice undergoes a topological transition from a strong topological insulator to a weak topological insulator at a finite temperature $T_D$. At $T_D$, massless Dirac points emerge and the Kondo lattice becomes a Dirac semimetal [4]. Our analysis based on a slave-boson approach indicates that the emergent relativistic symmetry dictates nontrivial thermal responses over large parameter and temperature regimes. In particular, it yields critical scaling behaviors both in magnetic and transport responses near $T_D$. Our results are relevant for the topological Kondo insulator SmB$_6$ [5].

References:

Thursday, 10 August 2017
14.30-14.50
H1

020
Time quasicrystals in superfluid $^3$He

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¹Aalto University, Low Temperature Laboratory, Espoo, Finland, ²Landau Institute for Theoretical Physics, Chernogolovka, Russian Federation

The concept of time crystals, spontaneous reduction of continuous time translation symmetry to a discrete one, has recently attracted a lot of discussions [1,2]. It has been established that time crystals can be realized only in periodically driven systems, where response develops at a longer period, commensurate with the drive [3,4]. Here we report that in superfluid $^3$He-B, periodically driven with NMR excitation, a new type of response has been observed: part of the response has a longer, incommensurate period as compared with the drive, and the combined response is therefore quasiperiodic. This system can be called a time quasicrystal, realised as Bose-Einstein condensates of magnon quasiparticles. The appearance of the response at a longer period is not just a curious property but also has an important practical consequence. Frequency separation of the drive and the detection allows using those magnon condensates as sensitive and fast probes of various properties of the topological superfluid for instance in in-situ thermometry, in probing topological defects and their dynamics, and probing other spinwave modes [5-7].

References:
Thursday, 10 August 2017
14.30-14.50
G1

021
The symplectic Fermi liquid and its realization in cold atomic systems
Ramires A.
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We study the behaviour of fermions with large spin and SP(N) symmetry. We contrast their behaviour with the case of SU(N) symmetry by analysing the conserved quantities and dynamics in each case. We also develop the Fermi liquid theory for fermions with SP(N) symmetry. We find that the effective mass and compressibility are always enhanced in the presence of interactions, and that the N-dependence of the enhancement can be qualitative different in distinct parameter regimes of the interactions strengths. The magnetic susceptibility can be either enhanced or suppressed, with the larger effects present for small values of N. We conclude discussing what are the routes to realize SP(N) symmetry within cold atoms.

Thursday, 10 August 2017
14.30-14.50
G3

022
Quantum microwaves with a strong coupling QED open circuit
Mukharsky Y.1, Rolland .C.1, Westig M.1, Peugeot A.1, Parlavecchio O.1, Kubala B.1, Altimiras C.1,
Joyez P.1, Vion D.1, Roche P.1, Simon P.2, Holtheinz M.1, Trif M.2, Ankerhold J.A.3, Esteve D.1, Portier F.1
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3University of Ulm, Institute for Complex Quantum Systems, Ulm, Germany

Transport of elementary charge carriers across a circuit usually does not couple to the electromagnetic modes embedded in the circuit. We consider here a dc voltage biased Josephson junction in series with a microwave resonator. In this system, the effective coupling constant is the ratio between the resonator characteristic impedance , which can be engineered, and the relevant resistance quantum \( R_Q = \hbar / 4e^2 \sim 6.5 \text{ kOhms} \). At large coupling constant, the transfer of a single Cooper pair across the Josephson junction strongly couples to the circuit mode.

We show that, in the strong coupling regime, the transfer of a single Cooper pair only occurs when its energy \( 2eV \) can be transformed in \( 1,2,\ldots,n \) photons. We also identify a recently predicted regime for which the presence of a single photon blocks the creation of a second one, which prevents new excitation by Cooper pair tunneling until the resonator empties itself. Cooper pair transfer and photon emission are locked.

Using a two-mode resonator circuit with different frequencies, we demonstrate a regime in which the transfer of a single Cooper pair simultaneously excites a single photonic excitation in each mode. We demonstrate entanglement of these photons. [1].

References:
023
Scattering of phonons by atomic nano-bubbles in superfluid helium doped with dysprosium
Moroshkin P., Kono K.
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Foreign atoms injected in superfluid helium and resonantly excited by laser radiation can be used as sensitive probes for the elementary excitations in the quantum fluid and as tracers for the turbulent fluid flow. The dopants reside in nanometer-sized cavities, also known as atomic bubbles [1], whose vibration modes provide the coupling between the electronic transitions of the dopant and the excitations of the liquid (phonons) [2].

We present an experimental study of Dy atoms injected in superfluid He by means of laser ablation. The atoms are excited by a cw frequency-doubled Ti:Sapphire laser tuned to one of the transitions between the electronic configurations \(4f^{10}6s^2\) and \(4f^{9}5d6s^2\) (\(\lambda = 458.9\) nm), and the spectrally-resolved fluorescence is observed at several transitions originating from the lower lying excited states. The excitation spectrum obtained by scanning the laser wavelength displays a pronounced sharp zero-phonon line (ZPL) and a blue-shifted phonon wing (PW). The PW spectrum reflects the structure of the phonon wavepacket excited by the laser-induced atomic bubble vibrations and the spectral width of ZPL provides the measure for the rate of the phonon scattering by a non-vibrating atomic bubble.

References:

024
Anomalous asymmetry in melting and growth relaxations of \(^4\)He crystals after manipulation by acoustic radiation pressure
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We succeeded in manipulating the crystal-superfluid interface of \(^4\)He in desired orientations by acoustic radiation pressure and discovered that the relaxation times to the equilibrium state after the manipulation were very different between in melting and growth [1]. The melting relaxation was much slower than the growth relaxation. This asymmetry was apparent only on anisotropic surfaces like facets and vicinal surfaces, but did not show up on the isotropic rough surface. Furthermore, the melting relaxation exhibited a complicated behavior in multiple stages showing the anomalous shapes, such as needle or irregular shapes, depending on temperature, while growth relaxation was a simple one back to the initial flat surface in a single stage. These phenomena will be understood by taking into account the important role of superflow induced by anisotropic interface motion in the relaxation processes.

References:
Quantum spin liquid is a theoretical concept describing a disordered magnetic state with fractional spin excitations [1]. Its clearest realization is found in an exactly solved Kitaev honeycomb model where the spin fractionalizes into two types of anyonic - neither fermionic nor bosonic - excitations: gauge fluxes and Majorana fermions [2]. Using $^{35}$Cl nuclear magnetic resonance, we show that the candidate material $\alpha$-RuCl$_3$ [3] exhibits the key features of the ferromagnetic Kitaev model. Above and beyond the antiferromagnetically ordered phase at low temperatures and low magnetic fields, in the so called Kitaev paramagnetic phase [4], we observe a gapped spin-excitation continuum accompanied by the contrasting, monotonic negative temperature dependence of the magnetic susceptibility, together revealing the presence of fractional spin excitations [5]. Moreover, the excitation gap, observed to increase as a theoretically predicted third power of the applied magnetic field [2,6] with nonzero initial value, reveals the gauge flux mass and the field-induced mass of an otherwise massless Majorana fermion [5]. This is the first demonstration of the massive character of these two anyonic excitations, a crucial property for their potential application in topological quantum operations [2].

References:

Observation of the Flux Line Lattice in CeCu$_2$Si$_2$: implications for its pairing state
Forgan T. ¹, Blackburn E. ¹, Stockert O. ², Holmes A. ³, Cubitt R. ⁴, Riyat R. ¹
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Using small-angle neutron scattering, we have observed the flux line lattice (FLL) in the archetypical heavy fermion superconductor CeCu$_2$Si$_2$. For magnetic field parallel to the c-axis, we observe an almost undistorted hexagonal FLL, and the intensity of the signal rises, as the field is increased towards $H_{c2}$. The strengthening of the field contrast of the FLL as the field is raised is a clear indication of Pauli paramagnetic flux line cores, similar to those observed in the $d$-wave heavy fermion...
superconductor CeCoIn$_5$ [1]. This is an indication of Pauli limiting, which indicates even-parity pairing ($s$, $d$ etc). However, unlike CeCoIn$_5$, the FLL is hardly distorted at any field or temperature, and certainly never develops a square structure. We therefore conclude that this material is not a $d$-wave superconductor, despite being tetragonal and having magnetically mediated superconductivity.

References:

Thursday, 10 August 2017
15.20-15.40
G3

027
Correlations and entanglement of microwave photons emitted in a cascade decay
Gasparinetti S., Pechal M., Besse J.-C., Mondal M., Eichler C., Wallraff A.
ETH Zurich, Zurich, Switzerland

We use a three-level artificial atom in the ladder configuration as a source of microwave photons of different frequency. Our artificial atom is a transmon-type superconducting circuit, driven at the two-photon transition between ground and second-excited state. The transmon is embedded into a single-pole, double-throw switch [1] that selectively routes different-frequency photons into different spatial modes. We characterize the decay process for both continuous-wave and pulsed excitation. When the source is driven continuously, power cross-correlations between the two modes exhibit a crossover between strong antibunching and superbunching, typical of cascade decay, and an oscillatory pattern as the drive strength becomes comparable to the radiative decay rate. Using pulsed excitation, we prepare an arbitrary superposition of the ground and second-excited state and monitor the spontaneous emission of the source in real time. This scheme allows us to deterministically produce entangled photon pairs, as demonstrated by nonvanishing phase correlations and more generally by joint state tomography of the two itinerant photonic modes. [2]

References:

Thursday, 10 August 2017
15.40-16.00
G1

028
Decay dynamics of quadruply quantized vortices in a BEC
Telles G.¹, Fritsch A.¹, Vivanco F.¹, Tavares P.¹, Cidrim A.¹, Bareghì C.², Bagnato V.¹
¹University of Sao Paulo, Physics Institute of Sao Carlos, Sao Carlos, Brazil, ²Newcastle University,
JQC Durham-Newcastle, Newcastle upon Tyne, United Kingdom

Quantized vortices, topologically imprinted to dilute Bose-Einstein condensates (BECs), have been intensively studied in the last decade [1], contributing to the early studies carried out in standard superfluids and superconductors [2]. In this work, we present results from quadruply quantized vortices, which were topologically imprinted in $^{87}$Rb Bose-Einstein condensates [1], produced and held in a QUIC trap. We investigated the vortex complex split decay process using 2-axis absorption
imaging, and observed the spontaneous decay into four single charged vortices, shown in Fig.1. Moreover, we report the experimental observation of the twisted split decay of the quadruply charged vortices magnetically imprinted in the BEC. The observations were supported by numerical simulations showing that the process takes place in the shape of helical waves, finally splitting into separate singly-charged vortices as expected. We believe that the effect may be exploited to generate an almost isotropic state of turbulence.

[Fig.1: OD images (top); 1D profiles (bottom)]

References:
Electromagnetic waves in the terahertz (THz) frequency range (0.1~10 THz) have been recognized to be a fascinating area of research for the practical applications [1]. Lacking of compact THz emitters, so far, THz emitters based on the semiconductor technologies such as resonant tunneling diodes and THz quantum cascade lasers have rapidly been developed [2,3]. On the contrary, we have succeeded in generating THz waves (IJJ-THz emitter) using the stack of intrinsic Josephson junctions (IJJs) [4] existing in the single crystal of high-$T_c$ superconductor Bi$_2$Sr$_2$CaCu$_2$O$_{8+\delta}$ (Bi2212) [5,6,7]. The IJJ-THz emitter is made of the mesa structure of Bi2212 single crystals. The radiation frequency of this device is determined by the applied bias voltage to the IJJs according to the ac-Josephson effect and the radiation intensity is enhanced at characteristic cavity modes determined by the shape and the size of the Bi2212 mesa structures. Recently, in order to improve the device characteristics of the IJJ-THz emitters, we have developed a high heat exhausting structure from the mesa structures. We have obtained radiation frequencies from 0.3 to 2.4 THz and a few tens of microwatt level of output power by adjusting bias voltage conditions and sample temperatures [8].

References:

Thursday, 10 August 2017
15.40-16.00
Congress Hall

030
Direct evidence for an internal degree of freedom and broken time reversal symmetry in the B-phase of UPt$_3$

Eskildsen M.$^1$, Avers K.$^2$, Gannon W.J.$^3$, Kuhn S.J.$^1$, Halperin W.P.$^2$

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With three different mixed (vortex) phases UPt$_3$ is a paradigm for unconventional superconductivity, and a definitive understanding of the superconducting state in this material has remained elusive. The order parameter structure consistent with a number of experiments is an odd-parity, $f$-wave orbital state of $E_{2u}$ symmetry. This order parameter is chiral and breaks time reversal symmetry in the low-temperature B-phase.

We have performed small-angle neutron scattering studies of the vortex lattice (VL) in UPt$_3$ in the B- and C-phases with $H \parallel c$, finding a previously unknown field-induced VL rotation. The magnitude of the rotation show a subtle magnetic field history dependence; VLs prepared with the field parallel or anti-parallel with respect to initial direction for entry into the B-phase are rotated by different amounts. This suggests an internal degree of freedom associated with the vortex cores, and provides direct evidence for broken time reversal symmetry in the B-phase in non-zero fields by a bulk measurement. This corresponds to an order parameter chirality that is respectively in the same or opposite sense as the VL supercurrent circulation.
Supported by the USDOE Awards DE-FG02-10ER46783 (neutron scattering) and DE-FG02-05ER46248 (crystal growth and characterization).

Thursday, 10 August 2017
15.40-16.00
H1

031
Metallurgy of a quantum solid: plastic deformation of hcp $^4$He
Cheng Z.G, Beamish J
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In the elastic regime of solids, stress is proportional to strain and independent of strain rate. For larger strains the relationship becomes nonlinear, reflecting plastic deformations involving creep, yield, slip and work hardening. Most of these phenomena involve glide or climb of dislocations and, at large strains, their multiplication and entanglement. Here we report our observations of creep, slip, and yield in hcp $^4$He - a quantum solid with elastic moduli orders of magnitude lower than conventional solids and in which some dislocations are extraordinarily mobile. Above 0.6 K, the crystals deformed via thermally activated creep, with flow stresses that decreased when the temperature or strain rate was raised. At lower temperatures, sudden drops in stress appeared when the strain exceeded a threshold. These slip events reflect dislocation avalanches and were less frequent after repeated strain cycling, which suggests that dislocations multiply and entangle, effectively strengthening the solid (work hardening). Annealing the samples above 0.6 K, where creep is observed, restores the original behavior. We are studying the slip at temperatures as low as 20 mK, where the deformation is nonthermal and may reveal new quantum behavior involving dislocations.

Thursday, 10 August 2017
15.40-16.00
G2

032
Elementary excitations of fluctuating-stripe state in quantum spin chain
Pregelj M.¹, Zorko A.¹, Gomišek M.¹, Zaharko O.², Coomer F.³, Ivek T.⁴, Berger H.⁵, Arčon D.¹,⁶
¹Jozef Stefan Institute, Ljubljana, Slovenia, ²Paul Scherrer Institute, Villigen, Switzerland, ³ISIS Facility, Rutherford Appleton Laboratory, Didcot, United Kingdom, ⁴Institute of Physics, Zagreb, Croatia, ⁵Ecole Polytechnique Federal de Lausanne, Lausane, Switzerland, ⁶Faculty of Mathematics and Physics, University of Ljubljana, Ljubljana, Slovenia

Elementary excitations are a basic concept used to describe dynamical processes in condensed matter and are essential for explaining fundamental physical phenomena. Their variety is vast; ranging from established phonons and magnons to exotic magnetic monopoles [1] and Majorna fermions [2]. Yet, when order parameters intertwine, identification of elementary excitations is extremely difficult. For instance, the elusive excitations in high-temperature superconductors that propel enigmatic fluctuating-charge-stripe, i.e., electronic nematic, phases [3] are still unidentified.
Here we report on a new type of elementary excitations in a spin-stripe state, which occur as two perpendicular amplitude-modulated magnetic components with different modulation periods slide through each other. Exploring the frustrated zigzag spin-1/2 chain compound b-TeVO$_4$ [4,5] by muon-spin relaxation and dielectric spectroscopy, we find that the spin-orbit coupling introduces sizable anisotropic- and biquadratic-exchange interactions, which stabilize the spin-stripe phase and set the energy scale of underlying excitations. b-TeVO$_4$ thus offers a unique perspective on the stripe physics that avoids the problem of intertwining degrees of freedom, which hinders the research in high-temperature superconductors.

References:

Thursday, 10 August 2017
09.00-09.45
Congress Hall

033
Topological superconductors derived from topological insulators
Ando Y.
University of Cologne, Physics Institute II, Cologne, Germany

After the discovery of topological insulators (TIs), it was recognized that similar topological concepts can be applied to superconductors, which have an energy gap as is the case of insulators. Such a recognition led to the interest in topological superconductors as a new class of topological materials [1]. In this talk, I will discuss why the normal-state band structures of TIs provide particularly promising grounds for topological superconductivity. Both the 3D bulk band structure of a certain TI materials and the 2D surface band structure of TIs can be responsible for topological superconductivity. The superconductor Cu$_x$Bi$_2$Se$_3$ is an example of the former, and I will present accumulating evidence that this material realizes a peculiar topological superconducting state characterized by a “nematic” order parameter [2,3]. I will also discuss that the proximity-induced superconductivity on the surface of TIs provides a promising platform for realizing localized Majorana zero modes, which allow for encoding quantum information and could be used for topological quantum computation.

This project has received funding from the European Research Council (ERC) under the European Union’s Horizon 2020 research and innovation programme (grant No 741121) and from DFG (CRC1238 Project A04).

References:

Thursday, 10 August 2017
From roton to quantum droplets: dipolar quantum gases echo He superfluid phenomena

Ferlaino F.
University of Innsbruck, Innsbruck, Austria

With the tremendous advances in cooling and manipulation techniques, ultracold atomic gases have consolidated themselves as an ideal system to address fundamental questions in quantum fluid physics. Recently, we have produced Bose and Fermi quantum gases of dipolar character with ultra-cold Erbium atoms, which possess an unusually large magnetic moment. In the quantum regime, Er Bose-Einstein condensates feature two sources of interactions of genuinely different nature. The ordinary short-range van-der-Waals interaction combines with the long-range and anisotropic magnetic dipole-dipole interaction. The mere existence and competition between these two sources of interactions dictate the physics at play, disclosing a variety of intriguing phenomena in close connection to superfluid He.

This talk will provide an overview of some fascinating dipolar phenomena from the Innsbruck prospective, including the first observation of roton in the gas and quasi-self-bound quantum droplets.

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Fermi surface instabilities and field induced phenomena in ferromagnetic superconductors

Aoki D.
Tohoku University, IMR, Oarai, Japan

The coexistence of ferromagnetism and superconductivity is one of the most interesting topics in the correlated electron systems[1]. The microscopic coexistence is established in three uranium ferromagnets, UGe2, URhGe and UCoGe. The large internal field due to the ferromagnetism is not compatible with the superconductivity based on the spin-singlet state. Therefore the spin-triplet state is believed to be realized. Surprisingly the field-reentrant (reinforced) superconductivity is observed with the extremely large upper critical field. The unusual superconducting behavior is due to the ferromagnetic fluctuations and Fermi surface instabilities under magnetic field. The microscopic evidence for the ferromagnetic fluctuations is given by the NMR experiments. The Fermi surface instabilities at high fields are clearly observed in the quantum oscillations and thermopower measurements. We review our recent studies on URhGe and UCoGe with fine tuning field angle and pressure, focusing on the Fermi surface instabilities and field induced phenomena[2,3,4]. This work was done in collaboration with G. Bastien, A. Gourgout, B. Wu, G. Knebel, A. Pourret, D. Braithwaite, J. P. Brison, A. Nakamura, S. Araki, Y. Tokunaga, A. Nikitin, A. de Visser and J. Flouquet.

References:

The exotic ‘quantum critical’ physics that develops in the vicinity of quantum phase transitions is believed to underpin the fascinating behaviors of many strongly correlated electronic systems, such as heavy fermions and high temperature superconductors. However, the microscopic complexity impedes their quantitative understanding.

Tunable circuits could circumvent this obstacle. With a device implementing a quantum simulator for the three-channel ‘charge’ Kondo model [1], we explore the rich strongly correlated physics in two profoundly dissimilar regimes of quantum criticality [2]. The universal scalings, both toward different low-temperature fixed points and along the multiple crossovers from quantum criticality, are observed. Notably, we demonstrate an unanticipated violation of the maximum conductance for ballistic free electrons, in agreement with novel numerical renormalization group calculations.

References:
Thursday, 10 August 2017
09.45-10.30
H1

037
Experiments on quantum turbulence in superfluid $^4$He in the zero-temperature limit

Golov A.
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Manchester experiments on the generation and detection of tangles of vortex line in superfluid $^4$He at temperatures $T < 0.2$K, when the viscous normal component is virtually absent, are reviewed. In most of them, negative ions (electron bubbles), trapped by vortex lines and rings, are used to force and detect turbulence. Free decay of Vinen (unstructured) [1] and Kolmogorov (quasiclassical) [2] turbulence, as well as of their controlled mix [3], is observed and analyzed. The decay rate, its dependence on the polarization of vortex tangles, and mechanisms of energy cascade and dissipation at quantum length scales are discussed. Evidence for the change, below $T \sim 0.8$K, of the boundary conditions at solid walls from no-slip to free-slip is presented [2]. A finite critical amplitude of forcing for the transition to turbulence in steady rotation, i.e. from arrays to tangles of vortex line, is observed [4]. Attempts to investigate processes at quantum length scales and preparations for the visualization of vortex lines at $T < 0.2$K are outlined.

References:
standard models (superconductivity) cannot explain this phenomenon because the characteristic thermal energy is comparable to the Fermi energy in Bi and a new theory is necessary.

References:

Thursday, 10 August 2017
11.00-11.30
G3

039
Quantum coherent transport characteristics of two-dimensional semiconducting Bi$_2$O$_2$Se nanoplates
Meng M.$^1$, Huang S.$^1$, Wu J.$^2$, Jing Y.$^1$, Peng H.$^2$, Xu H.Q.$^{1,3}$
$^1$Peking University, Beijing Key Laboratory of Quantum Devices, Key Laboratory for the Physics and Chemistry of Nanodevices and Department of Electronics, Beijing, China, $^2$Peking University, Center for Nanochemistry, Beijing National Laboratory for Molecular Sciences (BNLMS), College of Chemistry and Molecular Engineering, Beijing, China, $^3$Lund University, Division of Solid State Physics, Lund, Sweden

Recently, the invention of 2D semiconducting Bi$_2$O$_2$Se nanoplates has attracted a lot of interest$^1$. CVD grown Bi$_2$O$_2$Se nanoplates possess not only a band energy gap $\sim$0.8 eV for logical circuits, but also is air-stable. The top-gate field effect transistors of Bi$_2$O$_2$Se nanoplates display excellent performance at room temperature, see Ref 1.

In this report, we systematically investigate the transport characteristics of a Bi$_2$O$_2$Se nanoplate. In a typical high mobility sample, $\sim$20000 cm$^2$/V×s at 2 K, we observe the Shubnikov-de Haas (SdH) oscillations, indicating great advantages as a host material for the exploration of novel quantum condensed states. On the other hand, the presence of weak disorders, introduced during material growth and device fabrications, may degrade the mobility. We study the coherent transport on Bi$_2$O$_2$Se nanoplates in terms of weak localization (WL) effect and universal conductance fluctuations (UCFs) in a weak disordered sample. The extracted phase-coherence length ($L$) reaches at $\sim$60 nm at 2 K, larger than the nanoplate thickness $\sim$ 9 nm and is proportion to $T^{-0.5}$, indicating the 2D transport nature. We also find that UCFs can survive in a length scale as far as 4.6 um. Our result may offer guide to help to design quantum device in Bi$_2$O$_2$Se nanoplates in the future.
Frustrated magnetism in strongly correlated oxides with large spin-orbit coupling

Gegenwart P.
Augsburg University, Institute of Physics, Augsburg, Germany

Frustrated magnets with competing interactions and anisotropies can host topologically non-trivial quantum ground states and spin excitations. We focus on model materials in the class of strongly correlated oxides with large spin-orbit coupling that will serve as experimental realizations of this intriguing physics. Magnetic properties of two- and three-dimensional honeycomb iridates [1,2] and rhodates [3], as well as the triangular mixed valence iridate Ba₃InIr₂O₉ [4] will be discussed. We also focus on the rare-earth based triangular quantum magnet YbMgGaO₄ [5,6].

Work in collaboration with A.A. Tsirlin, F. Freund, A. Jesche, R. Manna, S. Manni, I. Pietsch, Yuesheng Li, S. Choi, S. Williams, R. Coldea, P. Khuntia, M. Baenitz.

References:
1. S. C. Williams et al., PRB 93, 195158 (2016).
4. T. Dey et al., arXiv:1702.08305
5. Y. Li et al., PRL 117, 097201 (2016)
6. Y. Li et al., PRL 118, 107202 (2017)
importantly, color codes have a set of transversal gates which coincides with the set of topologically protected gates in Majorana-based systems, namely the Clifford gates. We illustrate the scheme by providing a complete description of a possible architecture.

References:

Thursday, 10 August 2017
11.00-11.30
G1

042
The quasiparticles in superfluid $^3$He near $T=0$ behave well for imaging, but where are they at supercritical velocities?

Pickett G.
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We have been studying the dynamics of the almost negligible gas of quasiparticles in superfluid $^3$He in the zero temperature limit ($T \sim 0.1T_c$). Of course the very low density implies ballistic collisionless transport for the quasiparticles, which coupled with the relative ease of detecting them, has allowed us to make increasingly sophisticated imaging experiments using a multi-pixel quasiparticle “retina”. For example we can “watch” pair breaking by a moving object as imaged on the retina. In that context the quasiparticle gas does what we want. However, surprisingly, at these low temperatures, the quasiparticle gas is too tenuous to provide a proper continuous “normal fluid” and thus the communication of movement in the quasiparticle gas is very poor. Moving surfaces go “undetected” by the superfluid, which very counter-intuitively allows dissipationless motion of moving objects in the superfluid well beyond the Landau critical velocity.

Thursday, 10 August 2017
14.00-14.30
Congress Hall

043
Intertwined orders in superconducting heavy-fermion CeCoIn$_5$

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1Los Alamos National Laboratory, MPA-CMMS, Los Alamos, United States, 2Paul Scherrer Institute, Laboratory for Scientific Developments & Novel Materials, Villigen, Switzerland

We present measurements of the thermal conductivity of heavy-fermion superconductor CeCoIn$_5$ in rotating magnetic field, that provide a clear evidence for intertwined orders in its high field superconducting (HFSC) phase [1]. Experiments were performed in a dilution refrigerator coupled with a superconducting magnet, allowing investigations down to 20mK and fields up to 14T. The sample, polished with a long axis in the [110] direction of tetragonal CeCoIn$_5$, nodal for its $d_{x^2-y^2}$ order parameter, was mounted with c-axis parallel to the horizontal axis of rotation of a piezo-electric rotator. Recent neutron scattering measurements [2] indicated that the SDW order in the HFSC phase is
single-domain. The ordering wave-vector $Q$ switches abruptly when magnetic field is rotated through the anti-nodal [100] direction, with $Q$ choosing the direction (node) more perpendicular to the magnetic field. The direction of $Q$ in our experiment, therefore, switches from being parallel to perpendicular to the heat current. The observed anisotropy of the heat current calls for a presence of a third order intertwined with the $d$-wave and SDW. A $p$-wave pair-density-wave, proposed to exist on theoretical grounds, can explain our results. An FFLO scenario[3], slightly modified, may also explain our results.

References:
mechanics, i.e. when the electron current becomes quantum itself. Using a tunnel junction between
normal metal contacts placed at ultra-low temperature as a quantum conductor, we demonstrate the
existence of squeezing as well as entanglement in the microwave radiation, thus proving that the
electron shot noise generates a quantum electromagnetic field. We measure the photon statistics of
that field, i.e., photon shot noise, that directly shows that the quantum conductor emits photons by
pairs.

Thursday, 10 August 2017
14.00-14.30
G1

046
Condensed matter, quantum fluids and quantum simulation
Le Hur K.
Centre de Physique Theorique, Ecole Polytechnique, Palaiseau, France

Quantum materials exhibit emergent collective behaviors giving rise to exotic quantum phases and
quantum phase transitions. The recent progress in « quantum control » in ultra-cold atoms,
nanotechnology and quantum electrodynamics circuits also allows to engineer many-body
Hamiltonians and quantum fluids of matter and light, with modern applications in quantum information,
Feynman simulation and quantum computation.

We will discuss at a general level a few relations between
- Emergent phases and quantum phase transitions
- Topological phases and gauge theories, Anderson Resonating Valence Bond States and
topological superconductivity, Mott physics and Magnetism
- Applications in « protected » quantum transport and quantum computing
- Sensing (dynamics, transport, light-matter phenomena, Floquet engineering)
- Quantum information perspectives, entanglement measures

The presentation will be based on reviews we wrote on related subjects. Co-authors
will be introduced in the presentation.
Visualizing chiral domain structure in a sheet of superfluid $^3$He-A by magnetic resonance imaging

Sasaki Y.$^{1,2}$

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The stable texture in a sheet of superfluid $^3$He-A under in-plane magnetic field is believed to be a uniform dipole-locked texture of parallel spin anisotropic vector $d$ and orbital anisotropic vector $l$ except for a slight distortion near the edge of the sheet. However, the real space images of the texture obtained by specialized magnetic resonance imaging revealed that they are easy to hold planar textural defects, which have no significant footprint such as visible satellite peak in the NMR spectrum. We have shown that they are the chiral domain walls in between domains with opposite chirality. Main part of the wall consists of dipole-locked soliton, in which the $l=d$ vectors rotate from a direction perpendicular to the sheet to the opposite direction over a distance comparable to a thickness of the sheet. The domain structure is rather stable at temperatures far below the superfluid transition temperature $T_C$. However, we find that at temperatures near $T_C$ the domain walls move spontaneously or under the influence of external flow. Thus we could marginally manipulate the chiral domain structure with flow, although we have never observed a texture without chiral domain walls.

NMR study of rotational and superconducting symmetry in URu$_2$Si$_2$

Kambe S.$^1$, Hattori T.$^1$, Sakai H.$^1$, Tokunaga Y.$^1$, Matsuda T.D.$^2$, Haga Y.$^1$, Walstedt R.E.$^3$

$^1$Japan Atomic Energy Agency, Advanced Science Research Center, Tokai-mura, Japan, $^2$Tokyo Metropolitan University, Department of Physics, Hachioji, Japan, $^3$University of Michigan, Physics Department, Ann Arbor, United States

In strongly correlated 5f-electrons systems, exotic electronic states appear due to the competition between itinerant and localized nature of the 5f electrons. The appearance of unconventional superconductivity within the hidden ordered state in URu$_2$Si$_2$ is a typical example of it. In this study, the rotational symmetry of the hidden ordered state and the superconducting gap symmetry are investigated by means of $^{29}$Si NMR. As previously reported [1-3], a rather weak breakdown of 2-fold rotational order is distributed in the basal plane of the hidden ordered state. The local 4-fold symmetry is consistently supported via the Ruderman-Kittel interaction between nearest-neighbor Si sites determined by the NMR spin echo decay in the present study. The origin of a muted 2-fold symmetry reported earlier will be discussed. Concerning the superconducting gap symmetry, the T-dependence of the Knight shift along the $a$ [4] and $c$ [5] axes indicates that singlet pairing (i.e. d-wave) is likely for the superconducting state of URu$_2$Si$_2$. This result also indicates the strongly anisotropic spin susceptibility ($\chi_c>>\chi_a$), consistent with the previous quantum oscillation measurements [6], which may also be characteristic of the hidden ordered state.

References:
Interfaces between different $^3$He phases are extremely rich physical systems. At low enough temperatures $^3$He interfaces support phase waves, like crystallization waves [1] or massless phase waves on the A-B interface [2]. The phase waves in $^3$He are very unusual due to a significant magnetic contribution from spin supercurrents to the inertia. These waves present unique, directly observable objects which violate the Equivalence principle postulating the identity between gravitational and inertial masses [3].

In our experiments on crystallization waves a quartz tuning fork placed in liquid helium near the liquid-solid interface was used as a displacement sensing element [4]. High quality factor of the fork made it possible to detect amplitude of surface oscillations down to 1 Å by measuring the detuning of the fork. Such sensitive detection allowed us to apply relatively low AC voltage to the capacitor used for excitation of the surface waves. This experimental configuration resulted in a record low, of the order of 20 pW, heat dissipation to the helium sample and allowed us to cool the $^3$He below 0.4 mK and to obtain the first evidence of the crystallization waves. We report also the results of preliminary measurements in a magnetic field.

References:
a sharp peak at phase $\pi$. We present recent experiments obtained on Bi nanowires inserted in a multimode superconducting resonator which can be interpreted along these lines.

References:
A. Murani et al. arXiv:1611.03526

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Thursday, 10 August 2017
14.50-15.20
G1

051
Creation of vortex solitons due to the motion of trapped electrons along quantized vortices

Walmsley P.\(^1\), Villois A.\(^2\), Salman H.\(^2\), Golov A.\(^1\)

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\(^2\)University of East Anglia, School of Mathematics, Norwich, United Kingdom

We have measured the mobility and limiting terminal velocity of electron bubbles (negative ions) sliding along vortex lines in superfluid $^4$He for a broad range of temperatures (0.1 - 1 K). This allows dissipative processes at small length scales to be probed, which can include drag exerted by an excess density of excitations in the vicinity of the vortex core; the scattering and generation of vortex waves and solitons; condensation of $^3$He impurity atoms onto vortex cores.

Using a Gross-Pitaevskii model, we simulate the dynamics of an ion trapped on a quantized vortex line. The fully 3D simulations reproduce the complex spatio-temporal dynamics and reveal that a soliton-ion complex forms on the vortex and this characterises the behaviour of the ion in the zero temperature limit. We interpret the experimental measurements below 0.7 K in terms of these novel excitations.

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Thursday, 10 August 2017
14.50-15.20
G2

052
Observation of magnetic fragmentation in pyrochlore spin ices

Lhotel E.
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Magnetic fragmentation is a new state of matter in which the magnetic moment fragments, leading to the superposition of a magnetically ordered phase and a persistently fluctuating one, which is a Coulomb phase [1]. This fragmentation can occur in spin ice, a correlated but disordered ground state governed by a local constraint, the ice-rule, when the density of magnetic excitations that locally violate the ice-rule, is large enough. These excitations, the magnetic monopoles, can then organise as a crystal of alternating magnetic charges resulting in the fragmentation of the magnetic moment.

I will present two examples of realization of this fragmentation mechanism in pyrochlore oxide materials. Firstly, I will focus on Nd$_2$Zr$_2$O$_7$, where we have observed fragmentation in neutron scattering experiments through the superposition of an all in-all out ordered state, with a reduced
magnetic moment, and a pinch point pattern, characteristic of the Coulomb phase [2]. The finite energy of the pinch point pattern points out the quantum origin of the fragmentation in this system [3]. Secondly, I will present our results on Ho$_2$Ir$_2$O$_7$, where we have shown that fragmentation of the Ho magnetic moment can be produced by the injection of magnetic charges through the iridium molecular field [4].

**References:**


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Friday, 11 August 2017
11.30-11.50
G2

**053 Importance of virtual singlets in RVB theory of quantum spin liquids**

Ralko A.\textsuperscript{1}, Mila F.\textsuperscript{2}, Rousochatzakis I.\textsuperscript{3}

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It is well known that the low-energy sector of quantum spin liquids and other magnetically disordered systems is governed by short-ranged resonating-valence bonds. Here, we will show that the standard minimal truncation to the nearest neighbor valence-bond basis fails completely even for systems where it should work the most, according to received wisdom. This paradigm shift is demonstrated for both the quantum spin-1/2 square-kagome [1] and kagome [2] lattices, where the strong geometric frustration prevents magnetic ordering down to zero temperature. In the former, the shortest tunneling events bear the strongest longer-range fluctuations, leading to amplitudes that do not drop exponentially with the length of the loop, and to an unexpected loop-six valence-bond crystal, which is otherwise very high in energy at the minimal truncation level. In the latter, we will show from preliminary results [3] how the virtual singlets help in understanding the complex structure of the spin liquid of the RVB description of spin-1/2 kagome antiferromagnets by evidencing the proximity of a diamond-like crystal and making comparison with DMRG data.

**References:**


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Friday, 11 August 2017
11.30-11.50
G1

**054 Dynamics of surface Andreev-bound states and superfluidity beyond the Landau velocity in $^3$He-B**
Recently, it has been shown that superfluidity in $^3$He-B can survive in flows past objects at velocities far exceeding the critical Landau value [1]. The model supporting this phenomenon suggests that the Andreev-bound states on the surface of the moving object are emitted into bulk, causing dissipation only during acceleration. Meanwhile, the mechanism for breaking bulk Cooper pairs does not appear to exist for arbitrarily fast uniform motion in our experimental configuration.

We have developed a set of experimental techniques to measure the lifetime of the surface Andreev-bound states (SABS) responsible for the dissipation. Our experimental results imply that we can empty certain SABS into bulk in a controllable manner and then observe as they are replenished. We were surprised to find the typical lifetime of SABS to be on the order of 10 milliseconds.

The experiments are performed in the temperature range of 150-220 microkelvin, where the bulk quasiparticle excitations are ballistic. Our measurements provide insight into the dynamics of interaction between the gas of Bogoliubov excitations in a 3D topological superfluid and the corresponding gas of 2D edge states.

References:

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Friday, 11 August 2017
11.30-11.50
Congress Hall

055 Effects of reduction annealing on the electron-doped cuprates revealed by ARPES and core-level spectroscopy
Fujimori A.\textsuperscript{1}, Horio M.\textsuperscript{1}, Takahashi A.\textsuperscript{2}, Mori Y.\textsuperscript{2}, Konno T.\textsuperscript{2}, Ohgi T.\textsuperscript{2}, Sato H.\textsuperscript{2}, Yoshida T.\textsuperscript{3}, Okazaki K.\textsuperscript{4}, Suzuki H.\textsuperscript{1}, Koshiishi K.\textsuperscript{1}, Ootsuki D.\textsuperscript{5}, Mizokawa T.\textsuperscript{5}, Ono K.\textsuperscript{6}, Kobayashi M.\textsuperscript{6}, Minohara M.\textsuperscript{6}, Horiba K.\textsuperscript{6}, Kumigashira H.\textsuperscript{6}, Anzai T.\textsuperscript{7}, Arita M.\textsuperscript{7}, Namatame H.\textsuperscript{7}, Taniguchi M.\textsuperscript{7}, Ideta S.\textsuperscript{8}, Tanaka K.\textsuperscript{8}, Yokoyama Y.\textsuperscript{9}, Takubo K.\textsuperscript{9}, Hisamoto Y.\textsuperscript{10}, Awaji H.\textsuperscript{11}, Koike Y.\textsuperscript{12}

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In the electron-doped cuprates with the T-type structure such as Nd$_2$CeCuO$_4$, superconductivity appears only after appropriate reduction annealing, but strong antiferromagnetic (AFM) correlation is known to persist even in the superconducting phase [1]. Recently, bulk crystals of (Pr,La)$_2$CeCuO$_4$ with Ce doping concentrations as low as x ~ 0.05 [2] and thin films of R$_2$CuO$_4$ (R = Nd, Pr) without Ce doping [3] have shown superconductivity by improved annealing methods.

We have performed systematic studies of the effects of the improved annealing methods on the T-type cuprates in bulk [4] and thin film forms by ARPES and core-level spectroscopic methods. By reduction annealing, the signature of AFM correlation was suppressed, the electron carrier concentration significantly increased, and the $T_c$ increased over a much wider electron concentration range than the previous reports. Our results indicated that, in addition to the removal of a small amount of apical oxygen atoms which suppress the superconductivity, a significant amount of oxygen
atoms should be removed from “regular” sites (in the block layer and/or the CuO$_2$ plane), thereby doping the system with a sufficient amount of electron carriers.

References:

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11.30-11.50
H1

056
Possibility of Cooper-pair formation controlled by multi-terminal spin injection
Ohnishi K.$^{1,2}$, Sakamoto M.$^1$, Ishitaki M.$^1$, Kimura T.$^{1,2}$
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Recently the ferromagnet (F) / superconductor (S) hybrid structure has been studied intensively since the interplay between superconductivity and ferromagnetism produces various intriguing phenomena[1]. However, in general, the magnetic proximity effect destroys the superconducting properties in the vicinity of F/S junction, resulting in the difficulty of the coexistence of the spin-polarized electrons and Cooper-pairs. In this work, by measuring the spin transport of a normal metal / superconductor bilayer film under the spin injection, we investigate the formation and de-formation processes of the Cooper pairs.

We fabricated three ferromagnetic Ni-Fe nanopillars, which are the dual spin injectors and the spin detector, on a Cu/Nb bilayer film. In this structure, because of the small volume of the nanopillars, the large spin current can be generated by minimizing the Joule heating. In addition, the magnitude of the spin current can be controlled by the magnetic configuration of the injectors.

By analyzing carefully the bias current and magnetic configuration dependences of the spin transports, we find that superconducting property can be suppressed by the spin current. This indicates that the formation process of the Cooper-pair can be affected by the spin current injected.

References:

Friday, 11 August 2017
11.30-11.50
G3

057
Tying quantum knots
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The theory of knots has a long history in mathematics and physics since Lord Kelvin proposed knots in ether as a model of atoms [1]. Although this proposal did not work in physical reality, it gave a birth to
mathematical study of knots [2]. Recent experiments have observed knots in a variety of classical contexts, including nematic liquid crystals, DNA, optical beams and water. However, no experimental observations of knots have yet been reported in quantum matter. We demonstrate the controlled creation and detection of knot solitons in the order parameter of a spinor Bose-Einstein condensate [3]. The observed texture corresponds to a topologically nontrivial element of the third homotopy group and exhibits the celebrated Hopf fibration, which unites many seemingly unrelated physical phenomena. The very good agreement between the experiments and theory provides conclusive evidence for the existence of the knot soliton. Our observations establish an experimental foundation for future studies of stability and dynamics of three-dimensional topological solitons within quantum systems.

References:

Friday, 11 August 2017
11.50-12.10
G1

058
Visualizing quantum turbulence in superfluid $^3$He-B using quasiparticles
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We present experimental studies of quantum turbulence in superfluid $^3$He-B, the coldest fermionic liquid available. While the flow of bulk superfluid must be irrotational, it can mimic classical turbulence by supporting singly quantised vortices. Measurements were carried out at low temperatures where the thermal excitations in the superfluid comprise ballistic quasiparticles. In addition to normal scattering fermionic excitations can undergo Andreev reflection, which underpins non-invasive imaging of structures present in the superfluid such as quantum vortices or textures. The topological structures in superfluid could be produced via analogues of cosmological processes, for example the Kibble mechanism, or by exceeding the Landau critical velocity and breaking the condensate. We created a 5x5 pixel quasiparticle camera operating at 150 microkelvin and show two-dimensional ‘images’ of a quasiparticle beam and of a tangle of quantised vortices (quantum turbulence), that we produced mechanically. Quasiparticle imaging techniques could be used to observe other defects and to investigate pair-breaking processes in $^3$He.

Friday, 11 August 2017
11.50-12.10
G2

059
Magnetism in a strongly interacting topological Kondo insulator
Peters R., Yoshida T., Kawakami N.
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Topological Kondo insulators are strongly correlated systems which form a topologically nontrivial hybridization gap at the Fermi energy [1]. Strong correlations have significant impact on the surface states which are protected by the topology. It has been shown that correlations are strongly enhanced at the surface, which can lead to a coexistence of light and heavy surface states or a Kondo breakdown at the surface [2,3]. However, as commonly observed in heavy fermion materials and Kondo insulators, strong correlations can also lead to a magnetic ground state by tuning parameters such as pressure or doping. Thus, it is natural to ask: What is the impact of a magnetic state on the topology and the topologically protected surface states.

We theoretically analyze a three-dimensional cubic Kondo insulator with nontrivial topology using real-space dynamical mean field theory. Depending on the model parameter, we are able to stabilize different magnetic states in this model. Although the time-reversal symmetry is broken by the magnetic state, we demonstrate that topological surface states can exist in this model, which are protected by the reflection symmetry.

References:

Friday, 11 August 2017
11.50-12.10
G3

060
Majorana bound states vs. Shiba states in artificially constructed magnetic Fe atom-chains on superconducting Re(0001)
Kim H., Palacio-Morales A., Poskke T., Wiesendanger R.
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A magnetic nanowire with non-collinear spin texture (NCST) on a s-wave superconducting (SC) substrate is a fascinating platform, which has been proposed for observing Majorana bound states (MBS). Recently, evidences for topologically non-trivial end-states were experimentally found for Fe chains on Pb(110) [1-4]. However, such self-assembled nanowires have unavoidable limitations, such as uncontrolled length and orientation, and intermixing of atomic species of the nanowire and the substrate during the annealing process. Here, we demonstrate the fully-controlled formation of atomic chains from individual magnetic Fe adatoms on the SC Re(0001) by atom-manipulation techniques at T=350 mK. Spin-polarized STM results indicate the presence of a NCST, stabilized by interfacial DM interactions similar to Fe chains on Ir(001) [5]. Tunneling spectra measured spatially resolved on the Fe-atom chain reveal the evolution of the local density of states inside the SC gap as well as the development of edge states at the ends of chain, which are distinguishable from trivial ones by increasing the number of atoms within the chain. The experimental results will be compared with model-type calculations supporting the interpretation of the spectroscopic signatures at the ends of the chains as MBS.

References:
061
The theory of long-range spin-singlet proximity effect for Josephson system with single-crystal ferromagnet nanowire
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The spin-triplet long-range superconducting proximity effect may arise in superconductor - ferromagnet (SF) structures if there are magnetic inhomogeneities. So, the first observation of the spin-singlet long-range proximity effect for clean SFS system (weak-link through the single-domain monocrystalline ferromagnetic Co nanowire) [1] became surprising. The theoretical model [2] explained this effect by the spin-orbit interaction. We propose another theoretical model of the long-range Josephson transport. We take into account the Fermi surface anisotropy and the mismatch between the electron effective masses of majority and minority spin bands. The effective renormalized exchange interaction becomes dependent on the quasiparticle momentum direction in nanowire and must be completely compensated under certain conditions; thereby it leads to long-range spatial extent of the supercurrent. With the Eilenberger-like equations, we calculate the critical Josephson current flow through nanowire. The long-range proximity effect [2] can be quantitatively explained within the proposed theoretical framework.

References:

Friday, 11 August 2017
11.50-12.10
H1

062
Nanoscale ordering in YBa$_2$Cu$_3$O$_{7-δ}$ nanowires
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It has been recently demonstrated that nanoscale Charge Density Wave (CDW) order is ubiquitous in the High-$T_C$ Superconductors (HTS) cuprate families, both electron and hole doped [1-2]. This local order is intertwined to pair density waves (PDWs), theoretically predicted in cuprates more than 20 years ago [3], which give a local modulation of the Cooper pair density. As a consequence of PDW, the absolute value of the critical current density may vary in different directions of the a-b planes. We have grown untwinned YBa$_2$Cu$_3$O$_{7-δ}$ (YBCO) thin films at different dopings and fabricated nanowires with lateral dimensions down to 65 nm, not far from the CDW coherence length. The nanowires are patterned at different angles $γ$ with respect to a reference in-plane direction of the substrate. We have used the measurement of the critical current density $J_C$ of the nanowires at various $γ$ (in the interval 0° - 180°) to reveal the possible existence of a PDW. The measurements have shown a clear cosinusoidal modulation of the $J_C$ for the narrowest wires which smears out for wider nanowire
dimensions. This experiment represents one of the first evidence of the existence of a pair density
wave in HTS [4], the first one in YBCO.

References:

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11.00-11.30
G3

063 Emulating Majorana fermions and their braiding by Ising spin chains
Schön G.1, Backens S.1, Shnirman A.2, Makhlin Y.3, Gefen Y.2, Mooij J.E.4
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We analyse the control of Majorana zero-energy states by mapping the fermionic system onto a chain
of Ising spins. Although the topological protection is lost for the Ising chain, the properties of this
system provide added insight into the nature of the quantum states. By controlling the local magnetic
field, the Ising chain can be separated into topological and non-topological parts. We propose
topologically non-protected) schemes which allow performing the braiding operation, and in fact also
more general rotations. We consider a T-junction geometry, but we also propose a protocol for a
strictly one-dimensional setup. Both setups rely on an extra spin-1/2 coupler included either in the T-
junction, or as part of the chain such that it controls one of the Ising links. Depending on the quantum
state of the coupler, this link can be either ferromagnetic or antiferromagnetic. The coupler can be
manipulated once the topological parts of the chain hosting the Majorana fermions are moved far
away. Our scheme overcomes limitations which are a consequence of the 1D character of the Jordan-
Wigner transformation. We also propose an experimental implementation of our scheme based on a
chain of flux qubits with a design providing the needed control fields.

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G1

064 Fermi liquid theory applied to a film on an oscillating substrate
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We have studied the motion of a thin film of liquid helium-3 on a transversely oscillating planar
substrate. The linear response of the fluid film to the oscillations of the substrate is calculated by
means of Landau’s fermi liquid theory. The response consists of a collective transverse zero sound
mode, as well as incoherent quasiparticle excitations of the degenerate fermions. We calculate
numerically the acoustic impedance of the film under a wide range of conditions relevant to normal state helium-3 at millikelvin temperatures [1]. Some cases of known experiments are studied but most of the parameter range has not yet been tested experimentally. The theory is formulated for an arbitrary bidirectional reflectance distribution function (BRDF) of quasiparticles from the surfaces. In order to test more general boundary condition than the combination of diffuse and specular scattering, we have used the lowest order correction in the spherical harmonic expansion of the BRDF. No spectacular deviation from the combination of diffuse and specular scattering is found.

References:

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12.10-12.30
H1
065
Proximity-induced superconductivity in a ferromagnetic semiconductor (In,Fe)As
Nakamura T.,¹ Le D.A.,² Hashimoto Y.,¹ Ohya S.,²,³ Tanaka M.,²,³ Katsumoto S.,¹,³
¹University of Tokyo, Institute for Solid State Physics, Kashiwa, Japan, ²University of Tokyo, Department of Electrical Engineering and Information Systems, Bunkyo-ku, Japan, ³University of Tokyo, Center for Spintronics Research Network, Bunkyo-ku, Japan

Coexistence of superconductivity and magnetism gives rise to unconventional phases such as FFLO or spin-triplet states [1, 2] not only in native superconductors but also in proximity effects. In ferromagnetic semiconductors (FMSs), the magnetism is mediated by charge carriers and the half-metallic nature is often found. Hence the interplay between the superconductivity and the magnetism is of great interest in them. Here we report proximity-induced superconductivity in an n-type FMS (In,Fe)As [3]. An (In,Fe)As (Fe 6%) film with Curie temperature of 120 K was grown by MBE. Nb electrodes with gaps from 0.6 to 1.5 µm along [-110] or [110] were deposited on the film. In all the junctions, differential resistance exhibits zero-bias dips. In the junction with the gap of 0.6 µm, the dip reaches zero and the critical current $I_c$ oscillates against the magnetic field $H$ as shown in the figure. $I_c$ takes maximum at $H = +20$ Oe, where the magnetization $M$ is positive and hence the flux in the junction area is much larger than the flux quantum at the maximum. Though the behavior is against common knowledge on conventional Josephson effect, it can consistently be explained by spin-triplet pairing in the FMS.
Spin nematic phase is an intriguing phase of quantum magnets where the bound magnon pair condenses. One of the most important issues around the spin nematic phase is how to detect the spin nematic order. It was recently pointed out theoretically that the inelastic neutron scattering (INS) cross section shows the excitation spectrum of the bound magnon pair [1]. However, the intensity of the INS cross section related to the bound magnon pair is reduced with increase of the field while the spin nematic phase often manifests itself under high fields close to the saturation field. Therefore, a detecting method of the spin nematic order effective at high fields is still strongly called for.

In this presentation, we discuss that the electron spin resonance (ESR) spectrum is a direct probe to the spin nematic order effective under high magnetic fields [2]. In contrast to INS, the ESR absorption
peak related to the bound magnon pair has larger intensity at higher fields. It was recently reported that the bound magnon pair was observed in an ESR experiment in the fully polarized phase [3]. Our result is not only consistent with the experiment [3] but also will open a further way for experimentally observing the condensation and dynamics of the bound magnon pair in the spin nematic phase.

**References:**


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**Friday, 11 August 2017**

**12.10-12.30**

**Congress Hall**

067

**Experimental detection of the anomalous dimension of the current in the strange metal of the cuprates**

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The strange metal in the cuprates remains an unsolved problem because no knock-down experiment has revealed unambiguously the nature of the charge carriers in the normal state. Recent theoretical scaling analyses of the DC and AC transport properties indicate that a consistent theory is possible only if the current has an anomalous dimension that is fairly large. Indeed this is striking because a textbook problem in field theory is to show that conserved quantities cannot have anomalous dimensions. I will first show how a conserved current can have an anomalous dimension. I will then show that if the current in the normal state of the cuprates has an anomalous dimension, then the Aharonov-Bohm flux through a ring does not have the standard $eBA/\hbar$ form, where $A$ is the area and $B$ the external magnetic field, but instead is modified by a geometrical factor that depends directly on the anomalous dimension of the current. We calculate the signal in square and disk geometries. In both cases, the deviation from the standard result is striking and offers a fingerprint about what precisely is strange about the strange metal.

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**Friday, 11 August 2017**

**14.30-14.50**

**G3**

068

**Observation of quantum state transfer from polarized photons to electron spins using optical Pauli blockade effect**

*Kuroyama K.¹, Larsson M.¹, Matuso S.¹, Fujita T.¹, Valentin S.², Ludwig A.², Wieck A.², Oiwa A.³, Tarucha S.⁴*

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Photo-generation of electron-hole pairs is a fundamental optical process that preserves the quantum number, and the concept can apply for quantum repeater with single photons and spins as qubits. The
photon-to-spin quantum state transfer has been demonstrated for numerous photons and electrons with light-hole excitation of a GaAs quantum well, but not yet for single photons and electrons [1]. Here we use a GaAs quantum dot to verify the quantum state transfer from single photon polarization to single electron spin by optical Pauli spin blockade [2]. We observe significant reduction of the quantum efficiency for the one-electron dot compared to the empty dot in photo-electron generation by single photons [3-5] of linear polarization parallel to the magnetic field (Fig.1), to the half in the heavy-hole excitation (highlighted by red) and to zero in the light hole excitation (highlighted by blue). The reduced efficiency is assigned to the Pauli effect for the one-electron dot, and the latter is assigned to resonant excitation of the lower-energy Zeeman sub-state of the light hole exciton from detailed spectroscopy measurement of photo-trapping quantum efficiency. The results indicate that coherent state transfer of the linear polarization to the photo-excited electron spin.

References:
Andreev reflection intermediated by spin-flip process is a necessary ingredient to induce superconductivity (SC) in spin-polarized states, which is known as the spin-triplet SC proximity effect [1,2]. This proximity has been studied in SC-ferromagnetic metal junctions to date but not in junctions of superconductor and spin-polarized states in semiconductors like spin-resolved QH states. Here we report an experimental study of Andreev reflection in junctions of spin-resolved QH bulk states in an InAs quantum well and NbTi superconductor. At 0 T we observe conductance enhancement in the SC bulk due to Andreev reflection. At 4 T the spin-resolved QH states emerge and we observe specific sub-gap features in the differential conductance, \( dI/dV \) versus. bias voltage, \( V_{sd} \) in the plateau-transition regime. Figure 1 shows \( dI/dV \) versus. \( V_{sd} \) at different gate voltages. As the filling increases in the transition regime, the sub-gap feature changes from a dip, to a peak, and to a dip. We use a two-channel model to reproduce the observed sub-gap feature and finally assign the emerging peak in the middle of the transition regime to Andreev reflection intermediated by the spin-flip process [3]. These results mean that the spin-triplet SC proximity can be induced in the spin-resolved QH state.
References:

Friday, 11 August 2017
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G1

070
Topological quantum criticality in confined superfluid $^3$He-B
Mizushima T.
We here study the topological aspect of the quantum critical point (QCP) in confined superfluid $^3$He-B. It has recently been demonstrated that the hidden discrete symmetry can protect the topological phase even in the presence of a magnetic field [1] and the hidden symmetry breaking occurs at the QCP. From the fermionic viewpoint, the symmetry breaking triggers off the topological transition and the Majorana fermion acquires the mass gap. From the bosonic viewpoint, the Ising order emerges at the QCP. To discuss the physics behind the QCP, we utilize the effective action comprised of surface Majorana Fermions and Ising order fluctuations. Using the effective field theory, we clarify that the fluctuation of the Ising order develops at the QCP, which simultaneously triggers off the fluctuation of the topological order. In the topological phase, the Ising order behaves as the pseudo Nambu-Goldstone boson. The softening of this bosonic mode occurs at the QCP, which is a manifestation of the dynamical instability of the ground state towards the Ising-ordered non-topological state. Here, we discuss the interplay between fluctuations of topological order and Ising order and clarify the connection to supersymmetry which is expected to emerge at the QCP [2].

References:

Quantum spin ice, modeled for magnetic rare-earth pyrochlores [1,2], has attracted current great interest as a promising candidate to host a U (1) quantum spin liquid [3], which accommodates gapped deconfined spinon and gapless analogous photon excitations with and without spin-ice monopole charges, respectively. Recent finite-temperature Monte-Carlo simulations on a minimal model have revealed a thermal crossover on cooling from a classical spin ice regime to a U (1) quantum spin liquid regime [4], as well as a monopole supersolid phase intervening the kagome spin ice and a fully polarized ionic monopole insulator under a [111] magnetic field [5]. Now, critical numerical tests of an emergence of the gapless charge-0 and gapped charge-1 excitation spectra as a compelling evidence of the U (1) quantum spin liquid strictly at the ground state are called for. Here, we report evidence of these excitations by means of quantum Monte-Carlo simulations strictly at the ground state [6]. The nature of a valence bond solid ground state at the 2/3 magnetization plateau associated with quantum kagome spin ice [5] is also clarified on the same pyrochlore model. Possible relevance to experiments is discussed.

References:
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072 Robust odd-parity superconductivity in the doped topological insulator NbxBi2Se3

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We present resistivity and magnetization measurements on pristine [1] and proton-irradiated [2] crystals demonstrating that the superconducting state in the doped topological superconductor Nb0.25Bi2Se3 is surprisingly robust against disorder-induced electron scattering. The superconducting transition temperature $T_c$ decreases without indication of saturation with increasing defect concentration, and the corresponding scattering rates far surpass expectations based on conventional theory. The low temperature variation of the London penetration depth $\Delta \lambda(T)$ of pristine as well as irradiated crystals follows a power law $\Delta \lambda(T) \sim T^{2}$. Together, these results suggest the presence of symmetry-protected point nodes in Nb0.25Bi2Se3, and support the proposed odd-parity nematic $E_u$ pairing state [3]. Owing to strong spin-orbit locking, these results are the first demonstration of an unconventional superconductor that is robust against nonmagnetic disorder suggesting that topological superconductivity can be realized in rather dirty materials.

This work was supported by the U.S. Department of Energy, Office of Science, Basic Energy Sciences, Materials Sciences and Engineering Division. YSH acknowledges support from the National Science Foundation grant number DMR-1255607.

References:

Friday, 11 August 2017
15.20-15.40
H1

073 Supercurrent induced nonequilibrium effects in mesoscopic superconductors with Zeeman splitting
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Thermoelectric effects in ferromagnetic-superconducting hybrid structures have attracted a lot of interest in the last few years, due to the interesting physics revealed by the interplay between
superconductivity and magnetism. Huge thermoelectric effects were theoretically predicted[1] and experimentally observed[2] in such structures. Recently, a long-range spin accumulation in a ferromagnetic-superconducting hybrid structure with a strong Zeeman splitting was observed[3]. This unusual phenomena has been explained via the thermoelectric effect for Bogolubov quasiparticles in a spin-polarized superconductor[4]. However, the effect of the supercurrent was not discussed in these studies. Since the supercurrent induces a charge imbalance in the presence of a temperature gradient [5, 6], including the supercurrent in this structure causes some interesting thermoelectric effects, such as the spin Seebeck effect. We use the theoretical framework developed in Ref.[4] based on the quasiclassical Usadel-Keldysh formalism, include the supercurrent and spin supercurrent in the superconducting wire, and investigate the nonequilibrium effects in a mesoscopic superconductor with Zeeman splitting.

References:
Topological surface superconductivity induced by geometry in thin topological insulators

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We report the experimental evidence and theoretical finding of a new class of topological superconductors formed by pairing of strongly correlated surface electrons in thin topological insulators. Measurements on transport properties of the topological insulator single crystal Sb2Te3 nanoflakes are performed for sample thickness ranging in from 5 to 27 nm[1]. Steep drops of resistance are observed for a number of nanoflakes below 2 K, manifesting superconducting transitions. Experimental results show that without structural changes, superconductivity emerges only when the thickness of nanoflakes is less than 9nm. Furthermore, normal state conductivity and upper critical fields exhibit strong increase as the thickness decreases below 9nm. Theoretical analyses show that the strong thickness dependences origin from the hybridization of two surface Dirac fermions of nanoflakes. It is found that the superconducting transition temperature reaches the maximum when the thickness is around 6nm and the hybridization gap starts to form. Our results indicate that the pairing symmetry of the emergent superconductivity is dominated by p-wave and forms a new class of topological superconductors.

References:

[1] Wei-Han et al, arXiv 1608.05337

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Quantum phases of triangular-lattice spin-S XXZ antiferromagnets near saturation


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We study the quantum phases near the saturation of triangular-lattice antiferromagnets with XXZ anisotropy (generic $J/J_z$). The renewed interest for this system comes from the suggestion that a nontrivial coplanar phase, called $\pi$-coplanar or $\Psi$ phase, could be stabilized by quantum effects besides the well-known 0-coplanar (or V) and umbrella phases. For $S=1/2$, our previous cluster mean-field analysis [1] predicted that the $\pi$-coplanar state emerges for $1.6 \leq J/J_z \leq 2.2$. However, a recent exact-diagonalization study in Ref. [2] claimed that the $\pi$-coplanar state is absent. Here we first offer a counterargument to Ref. [2] by reconsidering the exact-diagonalization analysis with much larger system sizes and a careful identification of the low-lying eigenstates. We conclude that the distinction between 0-coplanar and $\pi$-coplanar is fundamentally impossible in the symmetry-preserving finite-size calculations at fixed magnon number. We also perform a cluster mean-field-scaling analysis for $S \leq 3/2$. The results are smoothly connected to the large-$S$ expansion results [3], and the quantum-classical crossover of the phase diagram shows that the $\pi$-coplanar phase exists for any $S$ except for the classical limit ($S=\infty$). The most quantum case of $S=1/2$ has the largest existence range in terms of $J/J_z$.

References:

Subharmonic oscillations in a driven superconducting resonator

Svensson I.M., Bengtsson A., Krantz P., Simoen M., Bylander J., Shumeiko V., Delsing P.
Chalmers University of Technology, Göteborg, Sweden

We have observed subharmonic oscillations in a microwave resonator. Our device is a superconducting coplanar waveguide resonator terminated by a SQUID, which provides a nonlinear inductance that can be controlled by an external magnetic flux or by an alternating current (AC) drive. We detect the output field quadratures at frequencies near the fundamental mode of the resonator. We show that when the SQUID is AC-driven at a frequency 3f, with amplitude exceeding an instability threshold, this results in three subharmonic states at frequency f (~5 GHz), which are red-detuned from the fundamental mode of the resonator. These three states have the same amplitude but different phases evenly spread out on a circle. Theory has been developed to explain this process, and it agrees well with the data. Downconversion occurs due to interaction between two modes of the resonator, via the SQUID nonlinearity, when the driving frequency is nearly resonant with a higher mode.

Thermal Hall conductivity of a nodal chiral superconductor

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Motivated by the suggestion that Sr$_2$RuO$_4$ is a chiral p-wave superconductor and the experimental observation of universal thermal conductivity at low temperatures indicating line nodes or nearly line nodes in the gap for this system, we evaluate the zero field thermal Hall conductivity of a chiral nodal p-wave superconductor. We show that this thermal Hall conductivity (in contrast to the diagonal component) is not universal in the low temperature limit but depends on impurity concentration and phase shift characterizing the impurities. This zero-field Hall thermal conductivity vanishes when the phase shifts are multiple of pi/2. However, under general circumstances, it is smaller than the universal diagonal thermal conductivity only by the factor ln(2Δ/γ), where Δ is the maximum superconducting gap and γ is the impurity band width. Numerically this is roughly 0.1-0.2 for available samples. Hence this value of the thermal Hall conductivity is quite large. In particular it is much larger than the expected edge state contributions. Measurement of this zero-field thermal Hall conductivity would be an unambiguous indication that Sr$_2$RuO$_4$ is a chiral superconductor.
In systems without the inversion symmetry, the I-V characteristics can show asymmetric behavior between positive and negative directions. It is called nonreciprocal current, and the most famous example is the p-n junction, where the inversion symmetry is broken by its structure. Even in bulk crystals, the nonreciprocal transport occurs, however, the amplitude is usually very small [1-5]. In this talk, we focus on the resistive regime of noncentrosymmetric superconductors, where the superconducting fluctuation conductivity is dominant [6]. As an example, we study the monolayer transition metal dichalcogenides MoS2 [7-9] theoretically, and show that the nonreciprocal current is dramatically enhanced compared to the normal regime, which is consistent with the experiment. This dramatic enhancement of the nonreciprocal current comes from the scale difference between the Fermi energy and the superconducting gap. Therefore, we expect that this enhancement occurs in any other noncentrosymmetric superconductors.

References:
in either system. Here we present our experimental results of mobility of a Wigner crystal (WC) on the free surface of the mixture. We found that, in the ballistic regime at low temperatures, the mobility is enhanced compared to the case of the specular reflection of $^3$He quasiparticles at the surface. This anomalous enhancement of the WC mobility indicates that the momentum transfer at the reflection is smaller than that of the specular reflection, and can be attributable to an unusual reflection associated with accommodation process of a $^3$He quasiparticle into the 2D $^3$He surface layer [2].

References:

Friday, 11 August 2017
15.40-16.00
G3

081
Reducing 1/f noise in superconducting resonators by surface spin desorption
de Graaf S.1, Faoro L.2, Burnett J.3, Adamyan A.3, Tzalenchuk A.1,4, Kubatkin S.3, Lindström T.1, Danilov A.3
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Reducing noise and decoherence in solid state quantum devices will enable enhanced performance of a wide range of sensors and circuits. However, such efforts have been largely inhibited by the lack of knowledge about the origin of this noise and decoherence. We correlate measurements of frequency (dielectric) noise and loss in superconducting resonators made from NbN on Al2O3 with ultrasensitive in-situ electron spin resonance (ESR) measurements on the same devices [1]. We find that after removing a large fraction of surface spins by a simple heat treatment, the magnitude of the dielectric noise is reduced by almost 10 times. Our data is in excellent agreement with a model for strongly interacting two-level systems [2,3], allowing us to attribute the origin of the dielectric noise to ESR-active slow two-level charge fluctuators on the surface of our devices. Here we show that surface spins directly affect the performance of high-Q superconducting resonators, and the chemical fingerprint of the ESR spectrum together with noise and loss data enables a whole new route to identifying the origin of noise in quantum circuits.

References:

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15.40-16.00
G2

082
Numerical study of the Kitaev-Heisenberg chain
Agrapidis C.E.1, van den Brink J.1,2, Nishimoto S.1,2

Agrapidis C.E., van den Brink J.1,2, Nishimoto S.1,2
In recent years, because of the emergence of candidate materials and the interest in the spin liquid state realization, there has been a growing number of studies on the Kitaev model, at first, and on the Kitaev-Heisenberg (KH) after. Adding the Heisenberg type interaction to the initial, exactly integrable, model is necessary and inevitable for any realistic description, but leads to spin frustration. Nevertheless, the vast majority of these studies is focused on 2-dimensional lattices, while research on the KH chain is lacking.

Motivated by this, we study the KH chain using the exact diagonalization and the density matrix renormalization group techniques. We present the phase diagram as a function of an angle parameter $\phi$, setting the Heisenberg interaction to $\cos\phi$ and the Kitaev one to $\sin\phi$. We identify six different possible phases; namely, Heisenberg, XY-spiral, $S_z$-ferromagnetic, ferromagnetic, XY and Néel phases, by calculating total spin, spin-spin correlations, correlation length, central charge, static structure factor, and the Néel, $S_z$-ferromagnetic and XY order parameters. Moreover, we investigate specific features of the dynamical structure factor in each phase. In addition, we present how the phase diagram changes under the application of a magnetic field.

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**Friday, 11 August 2017**

**09.00-09.45**

**H1**

**083**

**Superconductive electronics for voltage metrology**

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Josephson's discovery in 1962 of the quantum behavior of superconducting junctions enabled a revolution in precision voltage measurement that replaced electrochemical cells, which are artifact standards whose behavior depends on environmental conditions, with quantum-based standards that are intrinsically accurate. Many technological advances in junction fabrication, superconducting integrated circuit technology, bias techniques, and instrumentation were required to achieve the present generation of practical dc and ac voltage standard systems. Quantum-based 10 V programmable Josephson voltage standards and 1 V rms Josephson arbitrary waveform synthesizers are now used in a wide range of metrology applications, calibration laboratories and precision measurement experiments. For metrology and precision measurements, these two NIST systems, and others like them, are used for measuring dc and ac voltage, ac power, and impedance. They are also key instruments in precision measurement experiments of mass and temperature to determine more accurate values of the Planck and Boltzmann constants. I will review major technological advances with a focus on the superconducting devices and circuits and describe the current state-of-the-art in applications.

**References:**


A Rüfenacht et al., "10 volt automated direct comparison of two cryocooled programmable Josephson voltage standards," DOI: 10.1109/CPEM.2016.7540474.

Friday, 11 August 2017

084

Ion transport on the surface of superfluid $^3$He

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Superfluid $^3$He is a BCS type p-wave superfluid. Ions moving in the superfluid $^3$He scatter thermally excited quasiparticles and the transport properties are determined by the quasiparticle scattering. The $^3$He-A phase is characterized by the pseudovector field of Cooper pair orbital-angular-momentum, which aligns perpendicularly to the surface. This chiral symmetry breaking results in a skew scattering of quasiparticles from the moving ions. And hence, the anomalous Hall effect (AHE) of ion current occurs\textsuperscript{1}. Our observation of this AHE\textsuperscript{2} is quantitatively explained by the recent theory\textsuperscript{3}. Near the surface of $^3$He-B phase, on the other hand, low-energy quasiparticle subgap bound states form Andreev surface bound states (ASBS), which possess Majorana nature. We observed an excess scattering from the ASBS in the surface ion mobility, and the absence of depth dependence\textsuperscript{4}. Although the excess scattering did not accord with the naive Majorana picture of ASBS by contraries, Tsutsumi theoretically worked out this puzzle, recently\textsuperscript{5}. We now obtain a clear evidence for the surface Majorana fermions in the superfluid $^3$He-B phase.

References:


Friday, 11 August 2017

09.00-09.45

G3

085

Gate-induced two-dimensional superconductivity

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Recent technological advances of materials fabrication have led to discoveries of a variety of 2D superconductors at heterogeneous interfaces and in ultrathin films \cite{1}; examples include superconductivity at oxide interfaces, electric-double-layer interfaces, and mechanically exfoliated, molecular-beam-epitaxy grown, or chemical vapor deposited atomically thin layers. All these 2D superconductors have very high crystallinity in marked contrast with the conventional 2D superconductors with amorphous or granular structures, and thus provide opportunities for investigating the intrinsic nature of 2D superconductors, in terms of extremely weak pinning coupled with enhanced thermal/quantum fluctuations, and also of the broken spatial inversion symmetry.
Here we discuss a variety of peculiar properties of gate-induced superconductivity using electric double layer transistor (EDLT) devices. Vortex phase diagram in highly crystalline superconductors is very much distinct from the conventional ones due to the strong quantum fluctuation. Also, we succeeded in observation of magnetochiral anisotropy in superconducting transport owing to the broken inversion symmetry [2, 3]. Finally, tunneling spectroscopy revealed new aspects of gate induced superconductivity.

References:

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09.45-10.30
Congress Hall

086 Topological matter in the ultra-low-temperature laboratory
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The talk presents an overview of recent advances in the experimental studies of topological quantum matter realized by superfluid phases of $^3$He. A new window to the fascinating world of fermionic Majorana, Weyl and Dirac modes, of various bosonic modes, including analogues of the Higgs boson, and of topological structures of superfluid vacuum is opened by the progress in experimental techniques. One example is new superfluid phases engineered with nanostructured confinement, like the polar phase, which possesses Dirac node line in bulk and fermionic flat band at the surfaces. In the polar phase long-sought half-quantum vortices (HQVs) have been discovered. It turns out that HQVs survive transition to the A phase, where they may serve in future as a platform to study core-bound Majorana modes. Moreover, HQVs can be transferred to the B phase, where their pairs form structures similar to cosmic Kibble walls. Another development is ultra-sensitive probes based on Bose-Einstein condensates of magnon quasiparticles. In $^3$He-B they e.g. reveal production of light Higgs modes in vicinity of vortex cores and by topological surface spin currents. Magnon condensates are expected to bring new results also in the polar phase, where they have been recently successfully created.

Friday, 11 August 2017
11.00-11.30
Congress Hall

087 Superconductivity in the antiperovskite oxide Sr$_{3-x}$SnO
Maeno Y.$^{1,}$, Oudah M.$^{1}$, Ikeda A.$^{1,}$, Hausmann J.N.$^{1,2,}$, Yonezawa S.$^{1,}$, Fukumoto T.$^{2,}$, Kobayashi S.$^{2,}$, Sato M.$^{1}$.
Recently, we discovered the first superconducting “antiperovskite oxide” Sr$_{3-x}$SnO with the transition temperature of around 5 K [1]. Oxides with perovskite-based structures have been known as essential materials for fascinating phenomena such as high-temperature and spin-triplet superconductivity. The cubic perovskite oxides, $\text{ABO}_3$, also exhibit superconductivity as in SrTiO$_{3-x}$ and Ba$_{0.6}$K$_{0.4}$BiO$_3$. Perovskite oxides have their counterparts, antiperovskite oxides $\text{A}_3\text{B}O$ (or $\text{B}O\text{A}_3$), in which the position of metal and oxygen ions are reversed and therefore metallic B ions take unusual negative valence states. The parent compound (with $x = 0$) of the new superconductor, Sr$_3$SnO, possesses Dirac points in its electronic structure and is a candidate of a topological crystalline insulator. Furthermore, a possibility of a topological odd-parity superconductivity has been proposed upon hole doping [1]. In this presentation, we will report the properties of Sr$_{3-x}$SnO with improved superconducting characteristics. We envision that this discovery of the new class of oxide superconductors will lead an important progress in physics and chemistry of antiperovskite oxides consisting of unusual metallic anions.

This work was supported by the JSPS KAKENHI Nos. JP15H05852 and JP15K21717.

References:

Friday, 11 August 2017
11.00-11.30
G2

088
Fermi surface instabilities in ferromagnetic superconductors
Pourret A.1,2, Knebel G.2, Gourgout A.7, Bastien G.2, Aoki D.3, Floquet J.2
1University Grenoble Alpes, INAC-PHELIQS, Grenoble, France, 2CEA, INAC-PHELIQS, Grenoble, France, 3Tohoku University, IMR, Oarai, Japan

In highly correlated electron systems, one of the main issues is to understand the interplay of Fermi surface instabilities, magnetic fluctuations and quantum criticality through competing orders. Among them, two compounds are particularly interesting, UCoGe and URhGe, because they show the coexistence of two “antagonist” states of matter, ferromagnetism and superconductivity. The most fascinating aspect in UCoGe is the peculiar dependence of the upper critical field with an “S-shape”, for URhGe, it is the apparition of a reentrant superconducting phase around 12T. Recently, we put emphasis on the important role of the Fermi surface on the transport properties in these systems. Indeed, in UCoGe, several successive anomalies were observed under magnetic field (along the easy magnetization c-axis) in resistivity, Hall effect and thermoelectric power. The direct observation of quantum oscillations showed that these anomalies are related to topological changes of the Fermi surface, also known as Lifshitz transitions [1]. In URhGe with the field applied along the hard magnetization b-axis, a drastic change in the Fermi surface at the spin reorientation field ($HR = 11.75$ T) has been observed through thermoelectric power measurements [2].

References:
Friday, 11 August 2017
11.00-11.30
H1

089
Triplet spin-valves with half-metal manganites

Robinson J.
University of Cambridge, Materials Science, Cambridge, United Kingdom

Superconducting spintronics represents a new paradigm for information processing involving the coexistence of spin-polarization and superconducting phase coherence [1-3]. The pairing state and critical temperature (Tc) of a thin s-wave superconductor (S) on two or more ferromagnets (F) are controllable through the magnetization-alignment of the F layers. Magnetization misalignment leads to spin-polarized triplet pair creation, and since such triplets are compatible with spin-polarized materials they are able to pass deeply into the F layers and so, cause a decrease in Tc. Routine transfer of spin-polarized triplets to HMFs is a major goal for superconducting spintronics so as to maximize triplet-state spin-polarization. In my talk I discuss our recent results on magnetization-tuneable pair conversion and transfer of spin-polarized triplet pairs to the chemically stable mixed valence manganite La2/3Ca1/3MnO3 in a pseudo spin-valve device using in-plane magnetic fields [4].

References:

Friday, 11 August 2017
14.00-14.30
G2

090
CORE results for the Kagome antiferromagnet: spin liquid with p6 chirality

Auerbach A.
Technion – Israel Institute of Technology, Physics, Haifa, Israel

The spin 1/2 Kagome Heisenberg antiferromagnet is the most studied model of highly frustrated quantum magnetism. It found experimental realization in herbertsmithite, and both theoretical and experimental indications of describing a true two dimensional spin liquid. However, its correlations have not been yet resolved by the conflicting proposals of variational wavefunctions. Therefore, a systematic approach provided by Contractor Renormalization, (CORE) offers an alternative insight into the low energy excitations. We compute [1] the CORE interactions up to range 3 on the 12 site stars superlattice using exact diagonalizations of up to 36 spins. Errors due to longe range interactions are determined by comparison of ground state energy to DMRG. We confirm a singlet ground state with no broken translational symmetry (spin liquid). However, we discover the onset of p6 - two dimensional chirality symmetry breaking. This prediction is currently being tested by careful DMRG studies on large cylinders. Experimentally, the p6 chirality order parameter should split the optical phonons degeneracy near the zone center. Signatures of this effect may have been observed by recent infrared measurements [2]. p6 symmetry breaking may explain difficulties in DMRG convergence on wide cylinders.
References:

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H1

091
Ballistic edge states in Bismuth nanowires revealed by SQUID interferometry
Murani A.¹, Kasumov A.¹, Sengupta S.¹, Delagrange R.¹, Deblock R.¹, Chepelianskii A.¹, Bouchiat H.¹, Guéron S.²
¹Laboratoire de Physique des Solides Université Paris Sud, Orsay, France, ²Laboratoire de Physique des Solides Université Paris Sud Université Paris Saclay, Orsay, France

Reducing the size of a conductor usually decreases its conductivity because of the enhanced effect of disorder in low dimensions, leading to diffusive transport and to weak, or even strong localization. Notable exceptions occur when topology provides protection against disorder. For instance in the recently discovered two-dimensional Topological Insulators, perfect spin-momentum locking should forbid backscattering along the edge states, and lead to ballistic conduction. In this talk, I will present a direct signature of ballistic 1D transport along the topological surfaces of a single crystal bismuth nanowire connected to superconducting electrodes. This signature was obtained by exploiting the extreme sensitivity of the supercurrent-versus-phase relation (CPR). The sharp sawtooth-shaped CPR we find demonstrates that transport occurs ballistically along two edges of the nanowire, and confirms the predicted nearly perfect transmission of Cooper pairs through Quantum Spin Hall edge states. In addition, we show that a magnetic field can induce 0-pi transitions and phi_0-junction behavior, providing a way to manipulate the phase of the supercurrent-carrying edge states and generate spin supercurrents.

References:

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G1

094
Signatures of Majorana-Weyl Fermions in superfluid $^3$He-A
Sauls J.
Northwestern University, Physics, Evanston, United States

I discuss the relationship between broken symmetries and topology of the chiral ground state of superfluid $^3$He-A and the Fermionic states confined near surfaces, domain walls and mesoscopic defects. The low-energy Fermionic spectrum of thin films of $^3$He-A contains a branch of chiral edge states (Majorana-Weyl Fermions). The chiral vacuum hosts a mass current confined near the edge boundaries. For translationally invariant confining boundaries the vacuum edge current is given by $J = n_0 \frac{h}{4}$, where $n_0$ is particle density of bulk $^3$He. I will highlight several results: (i) the connection between the Majorana-Weyl spectrum on the edge and the chiral vacuum,
(ii) the absence of topological protection of the vacuum edge current to symmetry breaking perturbations,
(iii) the effects of hybridization of spatially separated Majorana-Weyl Fermions under lateral confinement, and (iv) their experimental signatures in heat and mass transport, as well as ion mobility experiment.

References:
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G1

095
Majorana quasiparticles in topological insulator, superfluid $^3$He-B
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Majorana quasiparticles were predicted as the edge state in topological isolators, and particularly in superfluid $^3$He-B. The heat capacity of bulk superfluid $^3$He-B decreases at cooling by exponential law, while the Majorana heat capacity should decrease by a power law. Consequently, the Majorana heat capacity should play a major role at very low temperatures. We have measured the heat capacity of superfluid $^3$He in two bolometers with different surface to volume ratio. We have found that the heat capacity of both bolometers deviates from the exponential law at cooling down to temperature of 100 µK. The additional heat capacity is proportional to the surface of bolometers and corresponds quantitatively to a prediction for Majorana heat capacity. We succeed to get the conditions, when the Majorana heat capacity is even bigger than the bulk heat capacity in 3 times. The results of our experiments strongly support the theory of Majorana quasiparticles formations as an edge states in topological isolator superfluid $^3$He.

References:

Friday, 11 August 2017
14.50-15.20
H1

096
Heat transport through a Josephson junction
Golubev D., Faivre T., Pekola J.
Aalto University, Espoo, Finland

We discuss heat transport through a Josephson tunnel junction under various bias conditions. We first derive the formula for the cooling power of the junction valid for arbitrary time dependence of the Josephson phase. Combining it with the classical equation of motion for the phase, we find the time-averaged cooling power as a function of bias current or bias voltage. We also find the noise of the heat current and, more generally, the full counting statistics of the heat transport through the junction. We separately consider the metastable superconducting branch of the current-voltage characteristics allowing quantum fluctuations of the phase in this case. This regime is experimentally attractive since
the junction has low power dissipation, low impedance, and therefore may be used as a sensitive detector.

References:

Friday, 11 August 2017
14.30-14.50
G2

097
Mott semimetal state emerging under DC current in Ca$_2$RuO$_4$

Maeno Y.$^1$, Sow C.$^1$, Yonezawa S.$^1$, Nakamura F.$^2$, Kitamura S.$^{2,4}$, Oka T.$^{4,6}$, Kuroki K.$^6$

$^1$Kyoto University, Kyoto, Japan, $^2$Kurume Institute of Technology, Kurume, Japan, $^3$University of Tokyo, Tokyo, Japan, $^4$Max Planck Institute for the Physics of Complex Systems, Dresden, Germany, $^5$Max Planck Institute for Chemical Physics of Solids, Dresden, Germany, $^6$Osaka University, Osaka, Japan

The Mott insulator is considered as an electron “solid” frozen due to strong electron correlations. It has a potential to become a good metal if the electron solid melts by tuning of suitable stimuli. Chemical substitutions as well as pressure have been used extensively as such “tuning parameters” to induce novel electronic states of correlated electron liquids from Mott insulators.

In this talk, we will describe novel phenomena we found in the layered ruthenium oxide Ca$_2$RuO$_4$, for which non-equilibrium conditions introduced by DC electric field and current trigger and maintain the charge “liquid” state down to low temperatures [1].

When the electric current is not very strong, the Mott-gap can be tuned to disappear gradually. In such a condition, Ca$_2$RuO$_4$ exhibits a semi-metallic conduction and giant diamagnetism [2]. We will discuss how the partial Mott-gap closing leads to the emergence of a “Mott semimetal” state exhibiting such diamagnetic behavior.

The important implication of this study is that simple DC current may be used as a useful control parameter to induce entirely novel states from some Mott insulators.

This work was supported by the JSPS KAKENHI Nos. JP 26247060, JP15H05852 and JP15K21717.

References:

Saturday, 12 August 2017
09.45-10.30
Congress Hall

098
Nodeless and nodal topological crystalline superconductors

Sato M.

Yukawa Institute for Theoretical Physics, Kyoto University, Kyoto, Japan
After almost ten years since the discovery of topological insulators, the idea of topological phases has been widely accepted in a variety of condensed matter systems. Not only gapped materials but also gapless ones have been explored under the spell of topological phase. In particular, much efforts have been paid recently for searching topological crystalline phases, which acquire topological stability with the aid of crystalline symmetries. In this talk, I report our works on topological crystalline superconductors. First, I discuss possible topological superconductivity in Dirac semimetals [1-3]. Recent experiments have reported that doped Dirac semimetals show superconductivity in low temperature [3,4]. We show that doped Dirac semimetals naturally may host topological (crystalline) superconductivity due to the orbital mixing of Dirac points. Another topic is novel gapless topological phases in nonsymmorphic crystalline materials [5,6]. A nonsymmorphic crystalline symmetry is a symmetry obtained as a combination of point group operation and non-primitive lattice translation. I discuss that nonsymmorphic symmetry gives novel nodal superconductivity [5,6]. Furthermore, I present a systematic framework to explore topological crystalline phases in terms of K theory [6].

References:

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Congress Hall

099
BCS-BEC crossover and exotic pairing in FeSe
Matsuda Y.
Kyoto University, Department of Physics, Kyoto, Japan

There is growing evidence that superconducting semimetal FeSe (Tc=8 K) is deep in the crossover regime between weak coupling BCS and strong-coupling BEC limits [1]. Therefore FeSe offers a unique and fascinating platform to study the crossover physics. Here we discuss several unique features which may provide new insights into fundamental aspects of the crossover. First is the observation of giant superconducting fluctuations by far exceeding the standard Gaussian theory and a possible pseudogap formation above Tc [2]. Second is the electronic structure. FeSe is a compensated semimetal, and hence it is essentially multiband superconductor, which makes the crossover physics in FeSe distinguished from that in ultracold atomic gases. Third concerns the fate of the superfluid when the spin populations are strongly imbalanced [3]. We show the emergence of a distinct field induced superconducting phase with unprecedentedly large spin-imbalance. We also show that the superconducting gap is significantly anisotropic in both the nematic and tetragonal regimes of Fe(Se1-xSx), indicating exotic pairing interaction [4][5].

References:
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H1

100
Cascade electronic refrigerator using superconducting junctions in the sub kelvin regime
Nguyen H.1, Meschke M.2, Courtois H.3, Pekola J.2
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2Department of Applied Physics, Aalto University, Helsinki, Finland,
3Institut Neel, Universite Grenoble Alpes, CNRS, Grenoble, France

Micro-refrigerators that operate in the subkelvin regime are key devices in quantum technology. A well-studied candidate, an electronic cooler using normal-metal-insulator-superconductor (N-I-S) tunnel junctions, offers substantial performance and power. Operation of such electronic cooler is limited by the accumulation of hot quasiparticles in its superconducting leads, due to the low relaxation rate and thermal conductivity of the superconductor. We employ a second N-I-S cooling stage to thermalize the hot superconductor at the backside of the main N-I-S cooler. Not only providing a lower bath temperature, the second-stage cooler actively evacuates quasiparticles out of the hot superconductor, especially in the low-temperature limit. It results in a three fold temperature drop at bath temperature 300 mK on the normal metal at 1 nW power. We integrate this device with a dielectric silicon nitride membrane and transform it into a robust and versatile cooling platform for multiple practical purposes.

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G3

101
Quantum simulation with cold atoms
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1University of Innsbruck, Institute for Theoretical Physics, Innsbruck, Austria,
2Austrian Academy of Sciences, IQOQI, Innsbruck, Austria

In this talk we give an overview, and describe recent advances in realizing engineered quantum many-body systems with cold atoms. Topics of interest include analog quantum simulation with atoms in optical lattices: as an illustrative example we will focus on artificial magnetic fields for topological phases [1], and we describe in some detail protocols and experiments allowing direct measurement of entanglement entropies and entanglement spectra [2]. We illustrate the design of spin models with arrays of Rydberg atoms [3]. As an example, we describe the realization of quantum spin glasses with all-to-all connectivity in a novel architecture [4], which points towards building a coherent quantum annealer, or adiabatic quantum computer, to solve optimization problems with techniques developed in atomic quantum simulation. We conclude with a brief discussion of digital quantum simulation, which we illustrate with the recent experiment simulating Schwinger pair production as a 1+1 QED on an ion trap quantum computer [5].

References:
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Congress Hall

102
Emerging phenomena at the magnetic field-tuned superconductor to insulator transition
Kapitulnik A.
Stanford University, Physics and Applied Physics Departments, Stanford, United States

The magnetic-field tuned superconductor-to-insulator transition (H-SIT), along with the quantum-Hall liquid-to-insulator transitions (QHIT) are paradigmatic quantum phase transitions and among the best experimentally studied. While evidence continue to mount to the fact that these two phenomena are in the same universality class, key results in the QHIT were not previously identified in the case of H-SIT. Tuning the disorder of two-dimensional superconducting films, and studying the full resistivity tensor, our results show a stark difference between films exhibiting weak vs. strong disorder. In weakly disordered films, the superconducting state gives way to an "anomalous metallic phase" with a resistivity that extrapolates to a non-zero value, but with a vanishing Hall resistance. In the strong disorder limit a "true" H-SIT is observed, characterized by an emerging self-duality at the H-SIT, and the proximate insulating phase is fundamentally distinct from a conventional "Anderson insulator" in that the Hall resistance, rather than diverging, tends to a finite value as the temperature approaches zero [1]. These features are analogous to behaviors previously documented near QHIT, thus support the correspondence between the two problems as implied by the composite boson theory.

References:

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11.30-11.50
G1

104
Application of SQUIDs to ultra-low noise torque magnetometry in high magnetic fields
Arnold F.¹, Naumann M.¹, Lühmann T.¹, Hassinger E.¹,²
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Torque magnetometry is a key method to measure the magnetic anisotropy and quantum oscillations in metals [1,2]. Ultra pure materials are often present only in very small sample sizes. Therefore, in the case of strongly correlated metals with large Fermi surfaces and high cyclotron masses, high magnetic torque sensitivities are required at temperatures well below 100 mK and magnetic fields beyond 10 T. Here, we present a new broadband read-out scheme for piezo-electric micro-cantilevers and Wheatstone type resistance measurements in magnetic fields up to 15 T and temperatures down to 50 mK. By using a two-stage SQUID as null detector of a cold Wheatstone bridge, we were able to
achieve a magnetic moment resolution of $\Delta m = 2 \times 10^{-14} \text{J/T}$, outperforming conventional magnetometers by at least one order of magnitude in this temperature and magnetic field range.

References:

Saturday, 12 August 2017
11.30-11.50
H1

105
Superfluid $^3$He confined in nanoscale pores
Zimmerman A.M., Nguyen M.D., Halperin W.P.
Northwestern University, Evanston, United States

Theoretical investigations of the phase diagram of superfluid $^3$He confined in long nanoscale pores of ~200nm diameter have predicted a rich phase diagram, vastly altered from that of the bulk superfluid. Predictions show many new stabilized phases, including distorted A-like and B-like phases as well as the polar phase and a translational symmetry breaking spiral phase.[1] We report NMR measurements on superfluid $^3$He performed in 200nm co-aligned pores with lengths of 100µm in order to test these predictions.

This work was supported by the National Science Foundation, DMR-1602542.

References:

Saturday, 12 August 2017
11.30-11.50
G2

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Toward Mott transition in quantum spin liquid
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The effects of pressure on a quantum spin liquid are investigated in an organic Mott insulator $\kappa$-(ET)$_2$Ag$_2$(CN)$_3$ with a spin-1/2 triangular lattice [1]. The application of negative chemical pressure to $\kappa$-(ET)$_2$Cu$_2$(CN)$_3$ [2], which is a well-known sister Mott insulator, allows for extensive tuning of antiferromagnetic exchange coupling, with $J/k_B = 175 - 310$ K, under hydrostatic pressure. Based on $^{13}$C nuclear magnetic resonance measurements under pressure, we uncover universal scaling in the static and dynamic spin susceptibilities down to low temperatures $< 0.1k_BT/J$. The persistent fluctuations and residual specific heat coefficient are consistent with the presence of gapless low-lying excitations, in contrast to the gapped spin-dimer system $\kappa$-(ET)$_2$B(CN)$_3$ [3]. Our results thus demonstrate fundamental finite-temperature properties of quantum spin liquid in a wide parameter range.

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Superadiabatic population transfer realized with a three-level transmon qubit

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Quantum control by adiabatic pulses presents the advantage of robustness under errors in the control parameters, yet it is inherently slow. Here we present an implementation of the superadiabatic protocol [1] in a three-level system realized with a transmon superconducting circuit, where an additional control pulse is used to cancel the non-adiabatic evolution of the system. This enables the transfer of population from the ground state to the second excited state by stimulated adiabatic Raman passage [2] in only a few tens of nanoseconds, approaching the quantum speed limit. As a bridge between adiabatic and direct methods, superadiabatic concept allows a continuous interpolation between the speed and robustness of the population transfer. As a result, it is possible to choose an optimal protocol speed that meets the given robustness criteria. This is particularly important in the field of circuit quantum electrodynamics, where the acceptable duration of the protocol is limited by the coherence time.

References:

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Superconducting vortex cores in tilted magnetic fields

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Very low temperature Scanning Tunneling Microscopy STM probes the superconducting density of states at the surface as a function of the position. Vortex lattices and vortex cores have been largely studied using magnetic fields perpendicular to the surface[1]. Since the seminal experiments by Hess et al in Bell labs during the late eighties, STM has given considerable understanding of the properties of vortices in many superconductors[1,2,3]. But Hess also provided measurements of vortex cores in tilted magnetic fields[4]. The properties of vortex cores in tilted fields have remained largely un-understood.

I will discuss new and extensive STM measurements of vortex cores in tilted fields in two different materials. In the simple isotropic s-wave superconductor $\beta$-Bi$_2$Pd it has been shown that vortices bend to exit perpendicular to the surface[5]. Also, under some circumstances, the intervortex
interaction in tilted fields is dominated by the stray magnetic field and not by bulk pinning[5]. In the anisotropic system 2H-NbSe$_2$, we present a systematic study of vortex cores in tilted fields and find oval shaped vortices[6]. I will compare these two situations with the well-studied case of crossing Abrikosov/Josephson vortex lattices of extremely anisotropic superconductors.

References:

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Tunable sub-gap radiation detection with superconducting resonators
Dupré O.¹, Benoît A.¹, Calvo M.¹, Catalano A.², Goupy J.¹, Hoarau C.¹, Klein T.¹, Le Calvez K.¹,
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Superconducting microwaves resonators are the building blocks of various technologies ranging from sensitive photon detectors for astrophysics to superconducting quantum devices. Kinetic Inductance Detectors (KIDs) are a particular implementation of superconducting resonators. They are state-of-the-art detectors for millimeter wave observations in astrophysics. The critical superconducting temperature $T_c$ imposes a working temperature $T < T_c$ and the superconducting gap $\Delta$ sets in the photon detector cutoff frequency to $h\nu > 2\Delta$. Within the BCS-superconducting theory $\Delta = 1.76 \text{ K} T_c$.

Thus, for classic KIDs lowering the cutoff frequency requires to lower accordingly the operating temperature.

We published a proof-of-concept of a disruptive technology for millimetric down to centimetric detection that we have called Sub-gap Kinetic Inductance Detectors (SKIDs) [1]. These detectors are sensitive to photons with an energy $h\nu$ laying well below twice the superconducting gap $2\Delta$. We show that the detected frequency can be adjusted by modulating the total length of the superconducting resonator. These devices are to be distinguished from the standard kinetic inductance detectors in which quasiparticles are generated when incident light breaks down Cooper pairs.

References:

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Tuneable surface scattering and $T_c$ suppression in superfluid $^3$He confined in a 200 nm nanofabricated slab geometry
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In unconventional p-wave superfluid $^3$He, Cooper pairs are subject to anisotropic pair breaking in the vicinity of surfaces and interfaces. This effect dominates when the superfluid is confined in a cavity of height comparable to the coherence length. This can be tuned from 80 nm to 15 nm by pressure. The surface pair-breaking depends on the boundary condition for surface scattering of quasiparticles. Here we provide a direct experimental demonstration of the ability to tune the surface scattering in situ. We study superfluid $^3$He confined in a single nanofabricated 200 nm high cavity, using SQUID-NMR as a probe of superfluid order parameter. We make an accurate determination of the suppression of the superfluid transition temperature, $T_c$. We start from atomically rough solid $^3$He layers on the surfaces, which show the largest suppression resulting from diffuse (random) scattering with evidence of magnetic surface scattering. Pre-plating the surfaces with a solid $^4$He film shows diffuse scattering, in good agreement with the predictions of quasiclassical theory. Finally we coat the surface with a superfluid $^4$He film and demonstrate close to perfect specular scattering, with the almost complete elimination of $T_c$ suppression. Measurements of the gap suppression will also be discussed.

References:
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**Magnetic Structure of Coupled Spin Tube with Kagome-Triangular Geometry in CsCrF₄**

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When a theoretical model is realized in nature, small additional terms play important roles particularly in geometrically frustrated magnets. In case of a triangular spin tube, the two-dimensional network of the inter-tube interaction forms characteristic lattices. Among them Kagome-Triangular (KT) lattice is known to exhibit an enriched phase diagram. CsCrF₄ is a rare experimental realization of such a system, and we investigate the magnetic state in the compound by using neutron diffraction technique. The diffraction profile exhibited a quasi-120 structure with \( \mathbf{k} = (1/2, 0, 1/2) \) at the base temperature. The calculation of the ground state phase diagram reveals that a single-ion anisotropy and Dzyaloshinskii-Moriya interaction suppress the cuboc structure, leading to the appearance of the quasi-120 structure. A successive phase transition having an intermediate state represented by \( \mathbf{k} = (1/3, 1/3, 1/2) \) was observed. Discussion on the phase diagram suggested that partially ordered 120 structure is induced by thermal fluctuation.

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**Mesoscopic fluctuations in the interferometry of driven flux qubits**

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We investigate flux qubits driven by a biharmonic magnetic signal, with a phase lag that acts as an effective time reversal broken parameter. The driving induced transition rate can be thought as an effective transmittance, profiting from a direct analogy between interference effects at avoided level crossings and scattering events in disordered electronic systems. For time scales prior to full relaxation, but large compared to the decoherence time, this characteristic rate has been accessed experimentally and signatures of Universal Conductance Fluctuations-like effects have been analyzed and compared with predictions from a model that only accounts for decoherence, as a classical noise.¹ We here go beyond the classical noise model and solve the full dynamics of the driven flux qubit in contact with a quantum bath employing the Floquet- Born- Markov Master equation.² Within this formalism, the computed relaxation and decoherence rates turn out to be strongly dependent on both the phase lag and the dc flux detuning. In particular we demonstrate the Weak Localization-like effect in the averages values of the relaxation rate.³

Our predictions can be tested for accessible, but longer time scales than the current experimental times.
We use the torsional pendulum method to study the A-B transition between 0.1 and 5.6 bar in an annular nanofluidic flow channel with height of 1.08 micrometers. We focus on the phase transition between the chiral A-phase and the time-reversal-invariant B-phase, motivated by the prediction of a spatially-modulated (stripe) phase at the A-B phase boundary [1,2]. We map the phase diagram and observe only small supercooling of the A-phase, in comparison to bulk or when confined in aerogel, with evidence for a non-monotonic pressure dependence. This suggests that a new intrinsic B-phase nucleation mechanism operates under confinement, mediated by the putative stripe phase. We discuss new insights this brings to the mystery of B-phase nucleation. Both the phase diagram and the relative superfluid fraction of the A and B phases, show that strong coupling is present at all pressures because the superfluid fraction of the A phase is greater than that of the B phase at all pressures [3]. Strong coupling at all pressures has implications for the stability of the stripe phase.

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interesting phenomena such as multiphoton Rabi oscillations [1] and a single photon exciting two or more atoms [2]. Here, we show that single- and multiphoton frequency-conversion can be realized with two resonator modes coupled ultrastrongly to a single two-level atom [3,4]. Indeed, with this and similar setups we can make a complete table with translations between three- and four-wave-mixing processes in nonlinear optics and analogous deterministic realizations with single photons in USC systems [3]. Furthermore, we show that these setups also provide analogues for higher-harmonic and -subharmonic generation, multiphoton absorption, parametric amplification, and the Kerr and cross-Kerr effects [3]. We present a unified picture of how all these effects are realized via higher-order processes and calculate the relevant transition rates. All the proposed setups can be experimentally realized in circuit QED.

References:

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Current sensing noise thermometer for milli-Kelvin temperatures with optimized dc-SQUIDs for cross correlated readout
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Within our search for easy-to-use reliable thermometers for milli-Kelvin and micro-Kelvin temperatures we recently developed a noise thermometer, where the Johnson current noise of a massive cylinder of high purity silver is monitored simultaneously by two current sensing dc-SQUIDs. The Si-Chip carrying the two SQUIDS is glued directly onto the noise source. Operating both SQUIDS in voltage biased mode in 2-stage SQUID configurations allows to reduce the power dissipation as well as the noise of the SQUIDS to a minimum. By computing the cross-correlation of the two SQUID signals the noise contribution of the read-out is suppressed to a level which is marginal even at micro-Kelvin temperatures. To further increase the suppression we fabricated a new SQUID design with minimal mutual inductance of input and feedback coil. We compare the thermometer to a previously developed magnetic field fluctuation thermometer in the temperature range from 2.5 K down to 9 mK. Statistical uncertainties below 0.5 % are achieved within 10 s of measurement time. Within this uncertainty no self heating was observable at base temperature. This agrees with predictions from the thermal model of the thermometer, which suggests that self heating should be marginal even at temperatures well below 1 mK.
Photovoltaic chiral magnetic effect in a Weyl semimetal

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Dirac and Weyl semimetals, which host bulk gapless excitations obeying quasi-relativistic fermion equations, have attracted much attention recently in condensed matter physics, since the anomaly-induced currents are dissipationless; thus, they have potential applications to unique electronics. Among the anomaly-related effects, one of the most interesting phenomena is the chiral magnetic effect [1-4], which is magnetic field-induced electric current. We theoretically predict the photovoltaic chiral magnetic effect, which is induced by the effective magnetic field due to circularly polarized light [5]. In the low-light-frequency regime, we find that the effective magnetic field triggers a finite spin polarization and drives the finite charge current. On the basis of the Keldysh-Greens function, we show that a net current is obtained by applying circularly polarized light. The current is proportional to the effective magnetic field, in the form of the chiral magnetic effect. On the other hand, unlike other chiral magnetic effects [2-4], it is dissipative and extrinsic. For Ta compound Weyl semimetals, the current reaches a huge value of O(10^6)A/m^2. In contrast, higher-frequency light realizes a quasi-static Floquet state with no induced electric current.

References:
Ising-type magnetic anisotropy in CePd$_2$As$_2$

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We investigated the anisotropic magnetic properties of CePd$_2$As$_2$ by magnetic, thermal, and electrical transport studies. X-ray diffraction studies confirmed the tetragonal ThCr$_2$Si$_2$-type structure and the high-quality of the CePd$_2$As$_2$ single crystals. Magnetization and magnetic susceptibility data taken along the different crystallographic directions evidence a huge crystalline electric field (CEF) induced Ising-type magneto-crystalline anisotropy with a large c-axis moment and a small in-plane moment at low temperature. A detailed CEF analysis based on the magnetic-susceptibility data indicates an almost pure $|\pm5/2>$ CEF ground state doublet with the dominantly $|\pm3/2>$ and the $|\pm1/2>$ doublets at 290 K and 330 K, respectively. At low temperature, we observe a uniaxial antiferromagnetic (AFM) ordering at temperature $T_N = 14.7$ K with the crystallographic c-direction being the magnetic easy axis. The magnetic entropy gain up to $T_N$ reaches almost $R \ln 2$ indicating localized 4$f$-electron magnetism without significant Kondo-type interactions. Below $T_N$, the application of a magnetic field along the c-axis induces a metamagnetic transition from the AFM to a field-polarized phase at $\mu_0 H_c = 0.95$ T, exhibiting a textbook example of a spin-flip transition as anticipated for an Ising-type AFM.

Probing a new time-reversal symmetry breaking phase in high-Tc superconductors

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Theory has long suggested that d-wave superconductors host low-temperature phases with spontaneously broken translational and time-reversal symmetries. Experimental verification of the associated spontaneous magnetic fields of such phases remains controversial, however. In a previous study [1], we showed that this could be due to finite-size effects tied to mid-gap states, with a symmetry-breaking phase manifested as a staggered vortex-antivortex structure. In this presentation, we look at the stability of this phase against an external magnetic field. We use the quasiclassical theory of superconductivity to study mesoscopic-sized superconducting grains with a d-wave order parameter. We find that under an external magnetic field [2], the vortex-antivortex phase competes with an intrinsic paramagnetic Meissner response. As the temperature is lowered, the strength of the vortices grows highly non-linearly, and the paramagnetic response is suppressed, making the phase robust against the external field. The competition gives rise to several macroscopic observables, and the phase transition is associated with a large jump in the heat capacity, serving as a hallmark for the phase to be observed experimentally.
Coherent modification of low-temperature thermal properties using phononic crystals

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Controlling thermal properties has become relevant in recent years, in light of the strong push to develop dissipation management and detection techniques [1]. Typically, phonon thermal conductivity is controlled by scattering, but much less attention has been given to coherent control by engineering the dispersion relations. Here, we discuss our recent experimental and computational advances for controlling thermal conduction [2,3] and heat capacity [4], using two-dimensional hole array phononic crystals (PnCs) at sub-Kelvin temperatures.

In our initial study [2], we observed a strong reduction of thermal conductance by a factor 30, with micron-scale periodicity. Further calculations [3] indicate that it can be reduced further with larger period arrays, or can even be increased by a factor ~3 with small period arrays. We have confirmed the further reduction experimentally in larger 4-8 μm period arrays, demonstrating the strange prediction [3] that larger dimensions lead to smaller thermal conductance. However, by increasing the period to 16 μm, no further reduction was seen, indicating that the coherent picture starts to be destroyed. We also demonstrate an analytic Debye-like metamaterial theory for the heat capacity of the PnCs in the low temperature limit.

References:
Superconducting SrTiO$_3$ features an extremely low charge carrier density and is ideal candidate for multiband superconductivity: with increasing doping, three electronic bands are successively filled, causing a superconducting dome in the phase diagram with critical temperature up to 0.4 K. Spectroscopic studies on superconducting SrTiO$_3$ are highly desired, but so far were limited to tunnelling, which is challenging due to the low carrier density. Here we present a new spectroscopic approach, namely optics at microwave frequencies (2 to 23 GHz) and mK temperatures using superconducting stripline resonators [1]. We obtain the complete electrodynamic response of superconducting SrTiO$_3$ and access both the quasiparticles and the superconducting condensate, and we determine the temperature dependence of the superfluid density and the superconducting energy gap for five samples throughout the superconducting dome. Surprisingly we find that only a single superconducting gap acts in SrTiO$_3$ [2], although at least two bands contribute (as we confirm by measurements in magnetic field). We can explain this finding with scattering that averages the superconducting gap structure, and this is consistent with an estimate for the transport relaxation rate based on our microwave data.

References:

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Electronic Fabry-Perot interference and the chiral angle: carbon nanotube structure determination from transport data
Dirnaichner A.$^{1,2}$, del Valle M.$^2$, Götz K.J.G.$^1$, Schupp F.J.$^1$, Paradiso N.$^1$, Grifoni M.$^2$, Strunk C.$^1$, Hüttel A.K.$^1$
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Connecting low-temperature transport spectroscopy features with a specific microscopic nanotube structure has been an elusive goal so far. While in Coulomb blockade many aspects of the discrete level spectrum are well-understood, a closer look leads to a fascinating (and puzzling) world of hard questions. Here, we apply a complementary approach [1] and analyze the Fabry-Perot interference pattern of a carbon nanotube strongly coupled to metallic leads [2]. By tuning a gate voltage over a large range, the trigonal warping of the Dirac cones at large energies can be probed. This, in combination with the valley degree of freedom, leads to a superstructure in the interference pattern, i.e., a secondary interference. Measurements on an ultraclean, long and suspended carbon nanotube device at millikelvin temperatures are complemented with tight binding calculations of the transmission for specific chiralities and analytic modelling. Taking symmetry classes of nanotubes [3,4], but also effects of symmetry breaking at the contacts into account, we show that the crucial parameter for the robust secondary interference pattern is the chiral angle. Consequently, the pattern provides valuable information for determining the structure of a carbon nanotube device.

References:
Microwave attenuator for reducing photon dephasing in superconducting qubits below 100 mK

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With recent improvements in the energy relaxation times of superconducting qubits, effects from dephasing have become more noticeable. To improve the thermalization of microwave input signals propagating to circuit-QED devices and reduce dephasing from the fluctuation of a non-equilibrium photon in and out of the read-out cavity [1], we have developed cryogenic broadband (1-10 GHz) microwave attenuators [2]. Our attenuators are fabricated in a coplanar waveguide geometry and formed from a thin film of dissipative nichrome and a thick film of silver acting as a heat sink for hot electrons. The attenuators have been quantified at millikelvin temperatures by measuring the dephasing rate of a 3D Al/AlO$_x$/Al transmon qubit which acts as a thermometer for non-equilibrium microwave photons. With a 20 dB attenuator strongly coupled to a 3D 8 GHz cavity at a temperature of 20 mK, the qubit dephasing rate is found to be $\Gamma_{\text{uni}} < 7000 \text{ s}^{-1}$ corresponding to an average number of cavity photons smaller than $10^{-3}$ or an attenuator noise temperature $T_n \leq 50 \text{ mK}$. In the limit of large dissipated power ($P_d > 1 \text{ nW}$), the cooling power of the attenuator is proportional to $T_n^{-5}$ ($T_n \approx 120 \text{ mK}$ at $P_d \approx 30 \text{ nW}$), suggesting that the cooling power is limited by the decoupling of hot electrons from the cold phonon bath.

References:

photo-conductivity response [1]. We show that due to the linearity of the coupled quantum systems such “quantum” features of the strong coupling regime, such as “avoided energy crossing”, the “vacuum” Rabi oscillations, suppression of “superradiance”, etc., can be accounted by a model based entirely on classical mechanics and electrodynamics. In addition, we observe strong photo-conductivity response of electrons at the harmonics of the cyclotron resonance, which arises from the scattering of the microwave-driven electrons from the ripples on the surface of liquid helium [2].

References:

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Electrical creation and control of spin current in 2D materials heterostructures
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Exploiting the spin degrees of freedom of electrons in solid state devices is considered as one of the alternative state variables for information storage and processing beyond the charge based technology. However, one of the primary challenges in this field is the efficient creation, transport and control of spin polarization. For this purpose, two-dimensional (2D) atomic crystals and their heterostructures provide an ideal platform for spintronics. Recently, we demonstrated a long distance spin transport over 16 µm and spin lifetimes up to 1.2 ns in large area CVD graphene [1]. In order to achieve an efficient spin injection into graphene, we further used h-BN tunnel barriers with large tunnel spin polarization up to 65 % [2]. More recently, we demonstrated gate control of spin polarization by employing graphene/MoS2 heterostructures [3]. Our findings demonstrate all-electrical spintronic device with the creation, transport and control of the spin current in 2D materials heterostructures, which can be key building blocks in future device architectures.

References:

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Superconductivity in the LaAlO3/SrTiO3 nanostructures
Kalaboukhov A.1, Aurino P.P.1, Galletti L.2, Bauch T.1, Lombardi F.1, Winkler D.1, Claeson T.1
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The discovery of a two-dimensional electron gas that exhibits superconductivity, ferromagnetism and large spin-orbit coupling in the interface between two wide band-gap insulators, LaAlO$_3$ and SrTiO$_3$ (LAO/STO), has stimulated increasing interest in both experimental and theoretical studies of this system [1]. There are indications that the conducting interface is strongly inhomogeneous on nanoscale [2]. In order to understand possible effect of the inhomogeneity on the superconducting state, we performed a systematic characterization of the LAO/STO nanostructures fabricated using our novel patterning method based on low-energy Ar+ ion irradiation [3]. We realized nano-rings and nano-wires with a lateral width of 100 - 300 nm. Analysis of current-voltage characteristics suggests that our nanostructures behave like clean superconducting filaments without formation of weak links. Moreover, we observed a SQUID-like periodic modulation of the critical current in nano-rings corresponding to the Little-Parks fluxoid quantization [4]. A most remarkable observation is enhancement of the critical current by a small perpendicular magnetic field. This effect may be explained by the suppression of spin flip scattering on magnetic domains by external magnetic field [5].

References:

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Strong coupling between an electron in a carbon nanotube quantum dot circuit and a photon in a cavity
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Circuit quantum electrodynamics allows one to probe, manipulate and couple superconducting quantum bits using cavity photons at an exquisite level. One of its cornerstones is the possibility to achieve the strong coupling which allows one to hybridize coherently light and matter. Its transposition to quantum dot circuits could offer the opportunity to use new degrees of freedom such as individual charge or spin. Recently, independent efforts to reach the strong coupling of quantum dot circuits to cavity photons have come to fruition with Si [1] and GaAs [2] double quantum dots, in parallel with our experiment using carbon nanotubes [3]. Specifically, we demonstrate a hybrid superconductor-quantum dot circuit which realizes the strong coupling of an individual electronic excitation to microwave photons. We observe a vacuum Rabi splitting 2g~10 MHz which exceeds by a factor of 3 the linewidth of the hybridized light-matter states. Our findings open the path to ultra-long distance entanglement of quantum dot based qubits. They could be adapted to many other circuit designs, shedding new light on the roadmap for scalability of quantum dot setups.

References:
Rotation speed dependent NMR frequency in superfluid $^3$He-A between parallel plates

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In superfluid $^3$He-A, it has been theoretically predicted that the half-quantum vortices (HQVs), whose winding number is 1/2, are stable in the order parameter configuration where the order parameters, l-vector and d-vector are perpendicular to each other [1]. The HQVs have not yet been observed in experiments with the parallel-plates sample cell in superfluid $^3$He-A [2, 3]. Recently, a theoretical calculation has suggested that the HQVs become stable under the specific cooling conditions through $T_c$ of a high magnetic field, a high angular velocity, and a temperature near $T_c$ [4].

We performed continuous-wave nuclear magnetic resonance (cw-NMR) measurements at 0.96 $T_c$ under a magnetic field of 27 mT by using the parallel-plates sample cell with 12.5 $\mu$m spacing at ISSP [5]. We observed that the negatively shifted resonance frequency depends on the angular velocity and found that the amount of negative shift becomes smaller with increasing angular velocity under some cooling conditions through $T_c$. Our numerical calculation also showed that the NMR frequency with HQVs depends on the angular velocity of rotation and the amount of negative shift becomes smaller with increasing angular velocity. Our experimental result is qualitatively similar to our calculation with HQVs.

References:
TTF)$_2$Cu(NCS)$_2$ and β´-(BEDT-TTF)$_2$SF$_6$CH$_2$CF$_2$SO$_3$. The existence of the phase transition is highly magnetic-field-orientation dependent, existing only for magnetic fields applied parallel to the 2D superconducting planes. In strong disagreement with previous calorimetric reports [1,2] but in good agreement with recent penetration depth [3,4] and NMR [5-7] measurements, we observe these phase transitions to occur at the Clogston-Chanrashekar paramagnetic limit $H_{Pauli}$ for each material. The location of the phase boundary, the order of the transition, and the extreme field-angle dependence are consistent with theoretical predictions [8,9] for a field-induced phase transition at $H_{Pauli}$ into an "FFLO" inhomogeneous superconducting state (in the absence of magnetic vortices within the superconducting planes).

References:

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Low-noise correlation measurements based on real time processing and cooled microwave amplifiers
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Shot noise is an important measurement quantity in various experiments in mesoscopic physics, providing information of the transport properties and internal energy scales of the sample [1]. Furthermore, shot noise correlations can be used to detect coherence phenomena, including Hanbury-Brown and Twiss effects and Cooper pair splitting [2-6]. We developed a microwave correlation measurement system based on real time processing [7]. To achieve low noise, we introduce an easy low-noise solution for cryogenic amplification at 600-900 MHz based on single discrete HEMT with 21 dB gain and 7 K noise temperature. In addition, we study the quantization effects in a digital correlation measurement and determination of optimal integration time by applying Allan deviation analysis. Finally, the low noise correlation measurement system is used to study the noise correlation of a graphene cross sample.

References:
132 Longitudinal qubit-resonator interaction in circuit QED
Krantz P.¹, Gustavsson S.¹, Yan F.¹, Campbell D.L.¹, Kjaergaard M.¹, Kim D.², Yoder J.², Grimsmo A.³, Bourassa J.², Blais A.³, Kerman A.J.², Orlando T.P.¹, Oliver W.D.¹,²
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We investigate an experimental implementation of a longitudinal interaction between a superconducting qubit and a half-wavelength coplanar microwave resonator. As opposed to the transverse coupling, commonly used when dispersively reading out qubits in circuit QED, the longitudinal coupling has several potential advantages, including reduced read-out times, absence of the Purcell effect, and increased signal-to-noise ratio (SNR). Instead of detecting a dispersive frequency shift of the resonator, the readout mechanism for our system is based on a parametric modulation of the qubit-resonator coupling that is on resonance with the resonator. This resonant modulation gives rise to a difference in amplitude between the two qubit states. To enhance this interaction and thus improve the state discrimination, we inductively couple the qubit to the resonator using an array of Josephson junctions placed in the center of the half-wavelength microwave resonator, which increases the participation ratio of inductance at the coupling point. I will present our latest experimental progress.

Friday, 11 August 2017
16.30-17.15
G3

134 Protecting quantum information in superconducting circuits
Devoret M.
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Can we prolong the coherence of a two-state manifold in a complex quantum system beyond the coherence of its longest-lived component? This question is the starting point in the construction of a scalable quantum computer. It translates in the search for processes that operate as some sort of Maxwell's demon, reliably correcting the errors resulting from the coupling between qubits and their environment. The presentation will review recent experiments that tested the dynamical protection, by Josephson circuits, of a logical qubit memory based on superpositions of particular coherent states of a superconducting resonator.
Topological order in magnetic materials

Pfleiderer C.
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A long history of intense research based on the notions of symmetry breaking and generalized rigidities have resulted in a remarkably comprehensive account of complex forms of magnetic order in condensed matter systems. In recent years a new facet of magnetism research receives increasing attention that concerns the topological character of magnetically ordered systems, notably those properties that remain unchanged under elastic deformations. Important examples include skyrmions, vortices and monopoles in chiral or frustrated magnets. These topological aspects of magnetic order are not only appealing from an esthetical and conceptual point of view, but offer strikingly simple explanations for materials properties that may seem to be surprising and hideously complicated at first sight. Several examples of topological order in magnetic materials will be presented, focusing on multi-k structures in chiral magnets and systems with centro-symmetric crystal structures.

From single magnetic adatoms on superconductors to coupled spin chains

Ruby M.‡, Heinrich B.W.‡, Peng Y.‡, Pientka F.‡, von Oppen F.‡, Franke K.J.‡
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Magnetic adsorbates on conventional s-wave superconductors lead to exchange interactions that can induce bound states inside the superconducting energy gap. These states are known as Yu-Shiba-Rusinov (YSR) states and can be resolved by scanning tunneling spectroscopy as a pair of resonances at positive and negative bias voltages in the superconducting gap.

Here, we employ tunneling spectroscopy at 1.1 K to investigate magnetic atoms and chains on superconducting Pb surfaces. We show that individual Manganese (Mn) atoms give rise to a distinct number of YSR-states, depending on the crystal field imposed by the adsorption site. The spatial extension of these states directly reflects their origin as the singly occupied d-states [1]. When the atoms are brought into sufficiently close distance, the Shiba states hybridize, thus giving rise to states with bonding and anti-bonding character. It has been shown that the Pb(110) surface supports the self-assembly of Fe chains, which exhibit fingerprints of Majorana bound states [2]. Here, we test, if Co chains on Pb(110) exhibit similar characteristics of ferromagnetic coupling and zero-energy states.

References:
Quantum liquid state of $J_{\text{eff}} = 1/2$ isospins in complex Ir oxides

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In 5d Ir\textsuperscript{4+} oxides, the spin-orbit coupling for 5d electrons is as large as $\sim 0.5$ eV and not small as compared with on-site Coulomb U. This often gives rise to a novel spin-orbital Mott state with $J_{\text{eff}} = 1/2$ isospins, which was first identified in the layered perovskite Sr\textsubscript{2}IrO\textsubscript{4} [1]. When $J_{\text{eff}} = 1/2$ iso-spins interact with each other through 90° Ir-$\text{O}_2$-Ir bonds, an Ising ferromagnetic coupling is expected [2]. In a-, b-, g-Li\textsubscript{2}IrO\textsubscript{3} with honeycomb based structure, $J_{\text{eff}} = 1/2$ iso-spin are connected by the three competing 90° Ir-$\text{O}_2$-Ir bonds. These compounds were pointed out theoretically to be a materialization of Kitaev model [3], where $S = 1/2$ spins on honeycomb lattice is connected by a bond dependent ferromagnetic interaction and a topological spin liquid with Majorana excitations is realized as the ground state. A long range magnetic ordering, however, was observed in a-, b-, g-Li\textsubscript{2}IrO\textsubscript{3}, which is likely due to the presence of additional magnetic couplings not included in the original Kitaev model [3]. The exploration of Kitaev spin liquid state was recently extended. We found that a quantum spin liquid state is realized in “hydrogenated” a-Li\textsubscript{2}IrO\textsubscript{3} and b-Li\textsubscript{2}IrO\textsubscript{3} under a high pressure [4]. The search for possible fractionalized excitations, expected for Kitaev spin liquid, is now underway.

References:
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Helium films: from strongly correlated atomically layered films to topological mesoscopic superfluidity

Saunders J.¹, Casey A.¹, Cowan B.¹, Heikkinen P.¹, Levitin L.¹, Nyeki J.¹, Parpia J.², Rojas X.¹, Waterworth A.¹, Zhelev N.²
¹Royal Holloway University of London, Physics, Egham, United Kingdom, ²Cornell University, Ithaca, United States

Helium films provide model systems for strongly correlated quantum matter and topological superfluidity. The top-down approach involves the confinement of topological superfluid $^3$He in engineered nanoscale geometries, with in situ tuneability of the surface scattering of $^3$He quasiparticles, which we have recently demonstrated. Specular surfaces enable us to approach the quasi-two-dimensional limit in slab-like cavities of sub-coherence length height. This opens up the study of topological superfluid $^3$He in height modulated structures, in which surfaces, edges and interfaces and their excitations, arising from bulk-edge correspondence, play a central role: topological mesoscopic superfluidity. The bottom-up approach is the investigation of helium films on the surface of graphite. We have recently identified a novel quasi-condensate in a $^4$He monolayer with intertwined superfluid and density wave order. The study of two dimensional $^3$He grown on superfluid $^4$He films allows the study of the potential instabilities of a 2D Fermi fluid, and we discuss recent results. Here the key features are the atomic layering of the films, and the ability to cool into the microkelvin regime. In this coupled fermion-boson system, interfacial excitations potentially play an important role.

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Physics of ultra-pure delafossite metals

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I will describe my group's research on a relatively little-studied but intriguing family of metals, the delafossite series of layered oxides. For reasons that are not perfectly understood, these materials have amazingly high electrical conductivity, with mean free paths of hundreds of angstroms (longer than even elemental copper or silver) at room temperature, growing to tens of microns at low temperatures. We are interested in them as possible hosts for hydrodynamic electronic transport, and investigate this by fabricating size-restricted microstructures using focused ion beam techniques. As layered materials that can be cleaved at low temperatures, they are also well suited to study by angle resolved photoemission spectroscopy, and host a variety of interesting surface states in addition to a
simple single-band bulk electronic structure. If time permits I will discuss our findings on non-magnetic PdCoO2, PtCoO2 and PdRhO2 and magnetic PdCrO2.

Saturday, 12 August 2017
11.00-11.30
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Chiral liquid phase near a quantum critical point
Wang Z.1, Starykh O.2, Chubukov A.3, Feiguin A.4, Zhu W.5, Batista C.D.1
1University of Tennessee, Physics and Astronomy, Knoxville, United States, 2University of Utah, Physics, Salt Lake City, United States, 3University of Minnesota, Physics, Minneapolis, United States, 4Northeastern University, Physics, Boston, United States, 5Los Alamos National Laboratory, Theoretical Division, Los Alamos, United States

Highly frustrated magnetic materials provide a natural test bed for exploring new phases. Although elusive for many years, exotic quantum states of matter are slowly appearing in several frustrated spin Hamiltonians. Different types of phases, including topological states, such as the time-reversal invariant $Z_2$ spin liquid, double-semion spin liquids, Dirac spin liquids, and chiral spin liquids, have been proposed to exist in frustrated quantum magnets. Although the number keeps increasing, in most cases these models are somewhat artificial and it remains unclear how to find experimental realizations. The purpose of this presentation is to show that quantum spin liquids, which only break discrete symmetries, such as chiral or nematic liquids, could appear under quite general conditions near a quantum phase transition between a quantum paramagnet and a magnetically ordered state. A necessary condition is that the magnetic ordering must break both continuous and discrete symmetries of the underlying model. This phenomenon can be exploited as a guiding principle in the ongoing experimental search for quantum spin liquid phases.

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Congress Hall

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Observation of topological superconductivity and Majorana fermions in superconducting ferromagnetic hybrid systems
Ménard G.1, Guissart S.2, Brun C.1, Leriche R.1, Debontridder F.1, Triff M.3, Roditchev D.4, Simon P.2, Cren T.5
1CNRS & Sorbonne University, Paris, France, 2Université Paris-Saclay, Orsay, France, 3Université Paris-Saclay, Orsay, France, 4ESPCI, Paris, France, 5CNRS & Sorbonne University, Institut des NanoSciences de Paris, Paris, France

Majorana fermions are very peculiar quasiparticles that are their own antiparticle. They obey non-abelian statistics: upon exchange, they behave differently from fermions (antisymmetric) and bosons (symmetric). Their unique properties could be used to develop new kind of quantum computing schemes. Majorana states are predicted to appear as edge states of topological superconductors. In
2D systems one expects to get some propagative Majorana edge states around the topological domains since the edges have a 1D character. The edge states in 2D topological superconductors are analogous to the edge states in Quantum Spin Hall systems. However, there is a very fundamental difference here as the superconducting topological edge states have the specificity of being Majorana excitations.

We will show that using sizeable magnetic disks made of Cobalt buried under a superconducting monolayer of Pb/Si(111), allows to generate topological superconductivity in 2D. We observe dispersive edge states crossing the gap all around the magnetic domains [1]. These spectroscopic features as signatures of a locally induced topological superconductivity in 2D Pb/Co/Si(111). We will show that a vortex generated in a topological domain support a localized Majorana bound state in its core.

References:

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Saturday, 12 August 2017
14.00-14.30
H1

143
Fermi liquid theory of vortex excitations and moving macroscopic objects in superfluid $^3$He-B
Thuneberg E.V.
University of Oulu, Nano and Molecular Systems Research Unit, Oulu, Finland

We consider several recent advances in the application of Fermi liquid theory to the normal and superfluid phases of liquid $^3$He. The stable vortex type in low temperature $^3$He-B has a structure where the core is split into two half cores. Numerical calculation of the structure reveals a Lifshitz transition in bound fermionic excitations circling the half cores [1]. In NMR the precessing magnetization induces oscillation of the vortex structure. The core excitations set a strong damping force on the oscillation of the core, allowing only slow rotation of the core. Instead, we find strong oscillation of the asymptotic structure of the vortex far from the core. This leads to radiation of spin waves and relaxation of the magnetization. The calculation of the relaxation based on spin wave radiation is in good agreement with measurements. In the normal state the Fermi liquid theory has been applied to calculate the forces on oscillating wires and surfaces [2]. These are now extended to the superfluid state to study motion at velocities exceeding the Landau critical velocity.

References:

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Saturday, 12 August 2017
14.00-14.30
G2

144
Exploring quantum spin-frustrated compound YbMgGaO$_4$
Zhang Q.
Renmin University of China, Beijing, China
The exploring of quantum spin-frustrated materials has attracted tremendous research interests and always been one of the frontiers in condensed matter physics for quite a long time, as quantum spin liquid (QSL) and many other exotic quantum spin states may be realized in this kind of materials. In this talk, I will introduce the exploring of a new spin-frustrated compound YbMgGaO$_4$, which possesses a perfect triangular spin lattice and strong spin-orbit coupling. By combining careful thermodynamics measurements and microscopic magnetic probes like muSR and neutron scattering, we demonstrate that the new compound is promising QSL candidates and favors a picture of U(1) gapless QSL.

References:
Yuesheng Li et al., Scientific Reports 5, 16419 (2015)
Yao Shen at al., Nature 540, 559-562 (2016)

Saturday, 12 August 2017
14.00-14.30
Congress Hall
145
Superconductivity and ferroelectricity in strontium titanate
Rischau C.W.$^1$, Lin X.$^2$, Grams C.P.$^2$, Finck D.$^2$, Harms S.$^2$, Engelmayr J.$^2$, Lorenz T.$^2$, Galais Y.$^3$, Fauqué B.$^1$, Hemberger J.$^2$, Behnia K.$^1$
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The large-gap semiconductor strontium titanate (SrTiO$_3$) becomes a metal upon removal of a tiny fraction of its oxygen atoms. The dilute metal has a sharp Fermi surface and is subject to a superconducting instability. Discovered half-a-century ago, the superconducting dome of strontium titanate remains doubly mysterious: How can superconductivity persist when there is only one carrier for $10^5$ atoms and the Fermi energy an order of magnitude smaller then than the Debye energy [1]? What destroys this cooperative order as soon as carrier density exceeds 0.02 electrons per formula unit?

On the other hand, substituting strontium with calcium stabilizes a long-range ferroelectric order in Sr$_{1-x}$Ca$_x$TiO$_3$. We find that in Sr$_{1-x}$Ca$_x$TiO$_3$ superconductivity coexists with metallicity and its superconducting instability in a narrow window of doping. As the carrier concentration is increased, the ferroelectric order is eventually destroyed by a quantum phase transition [2]. This happens at a critical doping level at which the Friedel oscillations generated by neighboring dipoles interfere destructively. In the vicinity of this quantum phase transition, the superconducting critical temperature is enhanced. We will discuss a possible link to ferroelectric quantum criticality [3,4].

References:

Saturday, 12 August 2017
Probing degeneracy, spin configuration and hybridization of gallium-arsenide based quantum dots

Maisi V.1,2, Hofmann A.2, Stockklauser A.2, Basset J.2, Gold C.2, Röösli M.2, Reichl C.2, Wegscheider W., Wallraff A.2, Ihn T.2, Ensslin K.2
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Degeneracies play an important role in quantum statistics and operation of any physical system. The degeneracy is typically determined by spatial symmetries and the spin degree of freedom. Moreover, hybridization of different quantum states influence on the energy level configuration and changes the degeneracy.

I present our experimental work where we have utilized single-electron electrometry to probe directly the degeneracy [1] and spin states [2, 3] of the discrete energy levels in GaAs quantum dots. Figure 1 represents a typical device that we study and the charge detector signal that reveals the electron tunneling events in the system. The tunnel events are strongly bunched because of spin blockade [2, 3]. I show furthermore how we achieved to probe the hybridization of two coupled quantum dots by measuring photon emission to a superconducting resonator [4]. Our results allow us to draw conclusions about the symmetries of our system and the mechanisms which cause spin-flipping such as the anisotropy of the spin-orbit interaction [3].

References:

A closed cycle dilution refrigerator for space applications

Haziot A., Triqueneaux S., Vermeulen G.
The Planck mission sub-K cooler was the so called open cycle dilution refrigerator (OCDR): incoming streams of liquid \(^3\)He and \(^4\)He mix in a Y-junction to produce cooling. Since the isotopes mixture was ejected into space, the amount of helium stored on the satellite set the limit of the cooling power (0.1 \(\mu W\) at 100 mK) and the lifetime (30 months). Future space missions (X-IFU, PIXIE) require an order of magnitude more cooling power, lower temperatures and longer lifetime. We are developing a closed cycle dilution refrigerator (CCDR) with a lifetime around 5 years and a cooling power up to 1 \(\mu W\) at 50 mK or 3 \(\mu W\) at 100 mK.

The CCDR design extends the one of the OCDR with an isotope separator (still) working at 1 K that allows to re-use the \(^3\)He and the \(^4\)He. Liquid \(^4\)He is extracted by a thermo-mechanical pump that uses the fountain effect of its superfluid phase, while almost pure vapor \(^3\)He is pumped thanks to the large difference in vapor pressure between \(^3\)He and \(^4\)He in the still conditions. The mixture in the still is confined in a porous material where capillarity forces replace gravity forces to form a liquid/vapor interface.

The results of the prototypes will be presented as well as the perspective demonstration model integrating a structure more suitable for space missions.

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**Saturday, 12 August 2017**

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**Real-space observation of surface-assisted orbital order in the heavy fermion compound CeCoIn\(_5\)**

**Yoshida Y.\(^1\), Kim H.\(^1,2\), Lee C.-C.\(^1,3\), Chang T.-R.\(^4\), Jeng H.-T.\(^4,5\), Lin H.\(^3\), Haga Y.\(^6\), Fisk Z.\(^6,7\), Hasegawa Y.\(^1\)**

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Orbital-related physics attracts growing interest in condensed matter research, but direct access to the orbital degree of freedom is challenging. Here we report the visualization of a surface-assisted orbital ordered structure on a cobalt-terminated surface of the heavy fermion compound CeCoIn\(_5\). With small tip-sample distance in our scanning tunneling microscopy, cobalt atoms are found to be dumbbell-shaped alternatingly in the [100] and [010] directions. A domain boundary of this ordered structure, which is localized within a terrace, denotes two-dimensionality of the ordered structure. First-principles calculations reveal that this structure is a consequence of the staggered \(d_{xz}-d_{yz}\) orbital order assisted by enhanced on-site Coulomb interaction at the surface. This novel surface-assisted orbital ordering seems to be ubiquitous in transition metal oxides, heavy fermion superconductors and other materials, but has been overlooked until now.

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**Saturday, 12 August 2017**

14.50-15.20
Properties and fate of multielectron bubbles in liquid helium

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Multielectron bubbles (MEBs) are cavities in liquid helium containing more than one electron. These objects provide a rich platform to study the properties of a two-dimensional electron system over a wide range of densities, as well as to investigate the effects of curvature. Although they have been predicted to show many interesting properties, the experimental progress has been relatively limited with most studies confined to their observation and measurement of charge. In a recent development, we have been able to trap [1] the MEBs in a Paul trap and subsequently measure their properties in a non-destructive manner. Our studies reveal the bubbles to be stable and long-lived under the presence of vapor inside the bubbles, which allowed us to study the effect of electric field [2] on the shape and dynamics of these objects. A question that naturally arises is what happens to the bubbles as the vapor condenses, and whether the MEBs are stable against shape perturbations. From the experiments carried out below the Lambda point, we conclude the MEBs to spontaneously break into smaller objects till they cannot be imaged any more. The final stable configuration appears to be bubbles containing very small (12) number of electrons, in accordance with recent theoretical [3] predictions.

References:
The coexistence of superconductivity and spin-polarization in the same system, showing also spin-orbit coupling, is of great interest for the emergence of novel quantum states in oxide 2DES.

References:

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G2

151
Doped Kondo chain - a heavy Luttinger liquid
Khait I.1, Azaria P.1,2, Berg E.3, Auerbach A.1

1Technion - Israel Institute of Technology, Physics Department, Haifa, Israel, 2Université Pierre et Marie Curie, Laboratoire de Physique Théorique des Liquides, Paris, France, 3Weizmann Institute of Science, Rehovot, Israel

We study the Kondo Lattice Model (KLM) in the paramagnetic metallic phase away from half-filling using Density Matrix Renormalization Group. It is commonly accepted that for a weak enough interaction between the conduction electrons and the localized spins a Tomonaga-Luttinger Liquid (TLL) is formed [1,2]. The TLL is characterized by a large Fermi Surface (FS) [3,4] consisting of the original conduction electrons and the localized spins. Previously, Friedel oscillations were used to determine the size of the FS, however contradictions between wave vectors of spin and charge oscillations did not resolve the nature of the large FS [5]. In the present work, we directly compute the density and spin susceptibilities which unambiguously reveal a large FS, and hence establish the TLL description of the KLM. We also find a hybridization gap at the small FS location and compare it to the large N (slave-boson) theory of the KLM.

References:

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G1

152
Vortex reconnections and decay of quantum turbulence in superfluid $^4$He: possible role of rotons and how to detect them
Galli D.E., Amelio I., Reatto L.
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Reconnections of vortices have a fundamental role in the decay of quantum turbulence in superfluid $^4$He. At low temperatures, emission of phonons and of small vortex rings generated by reconnections
and Kelvin wave cascades are commonly considered the channels for the dissipation of the turbulent energy but, at present, there is no direct experimental evidence for such processes. The theoretical evidence is based on phenomenological models and on the Gross-Pitaevskii equation (GPE). A microscopic study of a vortex reconnection requires to know the local structure of the vortex core, a region where GPE gives a poor representation of $^4$He. Recent ab initio many-body computations of a vortex line in superfluid $^4$He at T=0K have been performed [1]. For the Onsager-Feynman phase (equivalent to that of GPE) the exact energy and density profile are now known. Improved variational results have been obtained by assuming a more general form for the phase that accounts for backflow effects. Building upon these results we argue that a vortex reconnection leads not to a rarefaction wave as given by GPE but to emission of rotons. We estimate the number of rotons emitted in quantum turbulence and we propose a way to detect such non-thermal rotons based on the peculiar properties of superfluid $^4$He.

References:

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G3

153 Quasiparticle poisoning in Majorana island devices
van Veen J.1, Watson J.D.1, Protatki A.1, de Jong D.1, Sartori N.1, Binci L.1, Singh A.1, Karzig T.2, Pikulin D.I.2, Lutchyn R.2, Nygard J.3, Krogstrup P.3, Geresdi A.1, Kouwenhoven L.P.4
1QuTech and Kavli Institute of NanoScience, Delft University of Technology, Delft, Netherlands, 2Station Q, Microsoft Research, Santa Barbara, California, United States, 3Center for Quantum Devices and Station-Q Copenhagen, Niels Bohr Institute, University of Copenhagen, Copenhagen, Denmark, 4Microsoft Station-Q at Delft University of Technology, Delft, Netherlands

Over the past years numerous studies have reported on signatures of Majorana zero modes (MZMs) via zero-bias peaks, however, to date there have been no experiments demonstrating non-Abelian statistics. While a definitive proof of non-Abelian statistics would require a topological T-junction, it has recently been proposed that the fusion channels of MZMs, intimately related to the non-Abelian statistics, could be probed in a single-wire geometry [1]. An outstanding issue for a fusion experiment, however, is quasiparticle poisoning.

In our work we study quasiparticle poisoning using the gate modulation of the switching current in gate-tunable single Cooper pair transistors fabricated from InAs nanowires half-covered with an epitaxial Al shell. We find a 2e periodic modulation of the switching current in a wide range of gate voltages, nicely fitting the Joyez model [2]. Moreover, there was no sign of switching to the normal conducting state over a remarkably long timescale of 45 minutes. These results indicate the lack of deep quasiparticle traps on the island which is highly promising for the readout of the fusion experiment.

References:
Congress Hall

154
Fluctuations of nematicity and the spin subsystem in FeSe and FeSeS
Lin J.-Y.
National Chiao Tung University, Institute of Physics, Hsinchu City, Taiwan, Republic of China

The nematic order (nematicity) is considered one of the essential ingredients to understand the mechanism of Fe-based superconductivity. In most Fe-based superconductors (pnictides), nematic order is reasonably close to the antiferromagnetic order. In FeSe and FeSeS, in contrast, a nematic order emerges below the structure phase transition at $T_s = 90$ K (70 K for FeSeS) with no magnetic order. The case of FeSe is of paramount importance to a universal picture of Fe-based superconductors. The polarized ultrafast spectroscopy provides a tool to probe simultaneously the electronic structure and the magnetic interactions through quasiparticle dynamics. Here we show that this novel approach reveals both the electronic and magnetic nematicity below and, surprisingly, far above $T_s$ to at least 200 K. The quantitative pump-probe data clearly identify a correlation between the topology of the Fermi surface (FS) and the magnetism in all temperature regimes, thus providing profound insight into the driving factors of nematicity in both FeSe and FeSeS and the origin of its uniqueness.

Support from MOST of Taiwan is acknowledged.

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Interplay of the inverse proximity effect and magnetic field in out-of-equilibrium single-electron devices
1National Institute of Advanced Industrial Science and Technology (AIST), Tsukuba, Japan, 2Lancaster University, Department of Physics, Lancaster LA YB, United Kingdom, 3Institute of Solid State Physics, Vienna University of Technology, Wiedner Hauptstrasse, Austria, 4Aalto University, Low Temperature Laboratory, Department of Applied Physics, Aalto, Finland, 5Max Planck Institute for the Physics of Complex Systems, Dresden, Germany, 6Institute for Physics of Microstructures, Russian Academy of Sciences, Nizhny Novgorod, Russian Federation, 7National Research University Higher School of Economics, Moscow, Russian Federation, 8RIKEN Center for Emergent Matter Science, Wako, Japan

The proximity effect, which is the induction of the superconducting order into a normal conductor at the interface, plays an important role in the physics of solid-state devices [1,2]. In addition to this, the normal metal also affects the order parameter in the superconducting side via the inverse proximity effect.

Here we demonstrate the effect of an external magnetic field on non-equilibrium quasiparticle (QP) distribution in a single-electron hybrid device, under the conditions of the inverse proximity effect. Hot QPs that get trapped at zero field in the vicinity of the junctions, become released in a weak magnetic field, which creates additional QP traps in the leads. As a clear experimental evidence of the interplay of the inverse proximity effect and magnetic field, we observe an enhancement of the superconducting gap and significant improvement of the turnstile characteristics related to efficient QP relaxation in magnetic field. Theoretical calculations using the heat diffusion equation support this scenario.
quantitatively [3]. This mechanism of gap enhancement and efficient QP relaxation is important for understanding phenomena in various superconducting and hybrid devices and can be used for applications in quantum computation, photon detection and quantum metrology.

References:

Monday, 14 August 2017
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G2

156
Magnetic excitations with series expansion methods for Kitaev-Heisenberg models on honeycomb lattices
Yamada T., Suzuki T., Suga S.-I.
University of Hyogo, Himeji, Japan

Recently, honeycomb-lattice magnets such as α-RuCl₃ and Na₂IrO₃ have attracted much attention because of their novel properties. Although these materials undergo phase transitions to the zigzag antiferromagnetic states, their ground states are considered to be located close to the Kitaev spin liquid (KSL) state. We have revealed from the studies on dynamical structure factors of the Kitaev-Heisenberg (KH) model [1,2] that the linear spin-wave approximation fails in explaining low-lying excitations, when the magnetically ordered state is located close to the phase boundary to the KSL phase [3,4]. In this study, we investigate the ground-state phase diagram and low-lying excitations of the KH model using a cluster expansion method [5]. This method enables us to include effectively the interaction between magnon excitations. We calculate the ground state energies and the dispersion relations of low-lying excitations by changing the parameters from the region deep inside the magnetically ordered phase to the phase boundary of the KSL phase. We compare the dispersion relations obtained by this method with those obtained by a numerical diagonalization method, and discuss the characteristics of low-lying excitations close to the phase boundary.

References:
Catch and release of microwave phonons
Ekström M.K. 1, Aref T. 1, Sanada H. 1,2, Suri B. 1, Andersson G. 1, Delsing P. 1
1Chalmers University of Technology, Microtechnology and nanoscience, Göteborg, Sweden, 2NTT Corporation, NTT Basic Research Laboratories, Kanagawa, Japan

It has recently been shown that surface acoustic waves (SAWs) can interact with artificial atoms (transmon qubits) at the quantum level [1]. This has opened up for new possibilities utilizing SAWs (phonons) instead of electromagnetic waves (photons) [2-4] in quantum physics experiments. Here we explore one of these experiments; time-control of phonons. The time-control of propagating phonons benefits from the five orders of magnitude slower speed of SAWs than the speed of photons in vacuum. It takes the phonons about 200 ns to traverse from one transmon to a second transmon in our device. The transmons' coupling to the phonons can be tuned separately by applied magnetic flux and hence serve as tunable mirrors for individual phonons. The ample time it takes the phonons to traverse between the two transmons makes it possible to capture phonons and to on-demand release them in one desired direction. Since the phonons can traverse long distances, it should also be possible store them between the two transmons during a substantial time.

References:

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Instabilities of $^3$He on atomically layered $^4$He films
Waterworth A., Nyeki J., Cowan B., Saunders J.
Royal Holloway, University of London, Egham, United Kingdom

We report SQUID NMR measurements of the nuclear magnetic susceptibility of $^3$He on atomically layered $^4$He films on graphite at $^3$He coverages $n_3 < 1$ nm$^{-2}$, in the temperature range 200 µK to 500 mK. One motivation is to seek a regime, at low $^3$He densities, in which the $^3$He-$^3$He interactions are attractive, with a contribution from indirect interactions mediated by the $^4$He film [1,2]. The temperature independent Pauli susceptibility at sufficiently low temperatures provides a powerful way to characterize the ground state of the film. In practice we find this to be influenced by a rich interplay of competing surface states, condensation of $^3$He and phase separation into distinct and coexisting Fermi systems, with a clear dependence on the number of $^4$He layers and $^3$He coverage. Of particular interest is the possibility of $^3$He dimer formation [2,3,4]. On a three layer $^3$He film we observe a thermally activated temperature dependence of the susceptibility over a narrow range of $^3$He coverage, giving rise to a distinct maximum in susceptibility. Potential interpretations of this anomalous behaviour will be discussed.

References:
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**Insulating Josephson-junction chains as pinned Luttinger liquids**

Cedergren K.\(^1\), Ackroyd R.\(^1\), Kafanov S.\(^1\), Vogt N.\(^3\), Shnirman A.\(^4\), Duty T.\(^1\)

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Quantum physics in one spatial dimension is remarkably rich, yet even with strong interactions and disorder, surprisingly tractable. This is due to the fact that the low-energy physics of one-dimensional systems can be cast in terms of the Luttinger liquid. We have measured critical voltages for a large number of simple chains of sub-micron Josephson junctions with significantly varying energy scales. We observe universal scaling of critical voltage with single-junction Bloch bandwidth [1], strongly validating the quantum many-body theory of one-dimensional disordered systems [2,3]. In contrast to the presumed Mott insulator, this establishes the ground state of insulating Josephson junctions chains as a Luttinger liquid pinned by random offset charges, thereby providing a one-dimensional implementation of the Bose glass. The ubiquity of such an electronic glass in Josephson-junction chains has important implications for their proposed use as a fundamental current standard, which is based on synchronisation of coherent tunnelling of flux quanta (quantum phase slips)[4,5]. We have recently extended our measurements to SQUID chains and ladders, finding unexpected and tantalising behaviour.

**References:**


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**Spin space anisotropy in underdoped Ba(Fe\(_{1-x}\)Co\(_x\))\(_2\)As\(_2\) with coexistence of superconductivity and antiferromagnetism**

Waßer F.\(^1\), Lee C.-H.\(^2\), Kihou K.\(^2\), Steffens P.\(^3\), Schmalzl K.\(^4\), Oureshi N.\(^1\), Braden M.\(^1\)

\(^1\)Universität zu Köln, II. Physikalisches Institut, Köln, Germany, \(^2\)National Institute of Advanced Industrial Science and Technology (AIST), Tsukuba, Japan, \(^3\)Institut Laue Langevin, Grenoble, France, \(^4\)Jülich Centre for Neutron Science, Forschungszentrum Jülich GmbH, Oulstation at Institut Laue-Langevin, Grenoble, France

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**Spin space anisotropy in underdoped Ba(Fe\(_{1-x}\)Co\(_x\))\(_2\)As\(_2\) with coexistence of superconductivity and antiferromagnetism**

Waßer F.\(^1\), Lee C.-H.\(^2\), Kihou K.\(^2\), Steffens P.\(^3\), Schmalzl K.\(^4\), Oureshi N.\(^1\), Braden M.\(^1\)

\(^1\)Universität zu Köln, II. Physikalisches Institut, Köln, Germany, \(^2\)National Institute of Advanced Industrial Science and Technology (AIST), Tsukuba, Japan, \(^3\)Institut Laue Langevin, Grenoble, France, \(^4\)Jülich Centre for Neutron Science, Forschungszentrum Jülich GmbH, Oulstation at Institut Laue-Langevin, Grenoble, France
The emergence of a spin-resonance mode in the superconducting (SC) state provides strong support for a pairing mechanism based on spin fluctuations. For optimal and overdoped BaFe$_2$As$_2$ there are two resonance contributions: an isotropic mode at larger energy and an anisotropic mode at low energy. Several reports on Ni-, K-, and Co-doped samples suggest a rather general behaviour. On the other side the question of how static AFM influences the resonance mode has not been explored so far in any unconventional superconductor. Ba(Fe$_{0.955}$Co$_{0.045}$)$_2$As$_2$ is well suited for such study due to the well-established microscopic phase coexistence of AFM order and SC. We performed polarised inelastic neutron scattering experiments on Ba(Fe$_{0.955}$Co$_{0.045}$)$_2$As$_2$ [1], and with respect to the three orthorhombic directions, we observe three spin gaps in the AFM phase resembling those in BaFe$_2$As$_2$ [2]. Particularly, the longitudinal gap is large, and no spectral weight persists below the SC $2\Delta$ gap value. Consequently, in the SC state two fully anisotropic resonance modes without longitudinal contributions emerge in stark contrast to the optimal and over doping [3]. Band-selective properties in the AFM state must be taken into account to describe SC in materials with coexistence of SC and magnetic order.

References:

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X-ray fluorescence holography of Pr-doped CaFe$_2$As$_2$

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The state-of-the-art technique, x-ray fluorescence holography experiment [1], was performed in order to visualize the local 3D atomic configurations and positional fluctuations [2] of iron-based superconductor Ca$_{1-x}$Pr$_x$Fe$_2$As$_2$. Ca$_{1-x}$Pr$_x$Fe$_2$As$_2$ has been reported to exhibit high superconducting transition temperature $T_c = 49$ K with a very small superconducting volume fraction of several percent [3,4]. STM/STS observed a large superconducting gap around the doped Pr atoms, but no superconducting gap was observed around Ca [5]. In order to investigate the reason why the high $T_c$ superconductivity emerges around Pr, we performed x-ray fluorescence holography experiments using synchrotron radiation at BL13XU, SPring-8, Japan.

The atomic images of As revealed that As positions fluctuated significantly even in the parent CaFe$_2$As$_2$ compound without Pr doping. For Pr-doped Ca$_{0.9}$Pr$_{0.1}$Fe$_2$As$_2$, we found that the positional fluctuations of As were almost unchanged around Pr atoms compared with CaFe$_2$As$_2$, but the positional fluctuations of As were significantly increased around Ca atoms, which were located far from doped Pr. These observations were consistent with the local superconductivity at $T_c = 49$ K around the doped Pr.

References:
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Superfluid boundary layer

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We model the superfluid flow of liquid helium over a real surface, rough at the microscopic scale, derived from a wire used to experimentally generate turbulence and profiled by Atomic Force Microscopy. Our numerical simulations [1] of the Gross-Pitaevskii equation reveal that the sharpest features in the surface induce vortex nucleation both intrinsically (due to the raised local fluid velocity) and extrinsically (due to their role as pinning sites of vortex lines). Vortex interactions and reconnections contribute to form a well-defined, dense, turbulent layer of vortices with a non-classical average velocity profile and which continually sheds small vortex rings into the bulk. We characterise this behaviour for various imposed flows. As boundary layers conventionally arise from viscous forces, this result is surprising and opens up new insight into the nature of superflows at real boundaries.

References:

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Chiral spin liquids and anomalous Hall effect on the kagome lattice

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1Okinawa Institute of Science and Technology, Onna-son, Japan, 2RIKEN, Condensed Matter Theory Laboratory, Wako, Japan, 3University of Bordeaux, Laboratoire Ondes et Matières d’Aquitaine, Bordeaux, France, 4Gakushuin University, Department of Physics, Tokyo, Japan

Competing interactions in frustrated magnets prevent ordering down to very low temperatures and stabilize exotic highly degenerate phases where strong correlations coexist with fluctuations. We study the fully anisotropic nearest-neighbour model on kagome, whose ground state is described by a variety of exotic (chiral) phases, including classical spin liquids. When restricted to the XXZ model with Dzyaloshinskii-Moriya, our theory shows a three-fold mapping [1] which transforms the well-known Heisenberg antiferromagnet (HAF) and XXZ model onto two lines of time-reversal Hamiltonians. The mapping is exact for both classical and quantum spins, i.e. preserves the energy spectrums of the HAF and XXZ model. Therefore, our three-fold mapping gives rise to a connected network of quantum spin liquids centered around the Ising antiferromagnet. We show that this quantum disorder spreads...
over an extended region of the phase diagram at linear order in spin wave theory, which overlaps with
the parameter region of Herbertsmithite ZnCu3(OH)6Cl2. At the classical level, some of the phases
unveiled here support a spontaneous scalar chirality which was absent in the original HAF and XXZ
models.
The consequence of this scalar chirality on finite-temperature conductivity will be discussed [2].

References:

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Quantum coherently-driven charge transport across two SQUIPTs coupled by a Coulomb island
Enrico E. 1, Croin L. 1, Strambini E. 2, Giazotto F. 2
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Scuola Normale Superiore, Pisa, Italy

Actual research on the manipulation of quantum phenomena at the level of artificial atoms and qubits
mainly focuses on nanostructured superconducting circuitry.
We will present a device concept based on the exploitation of quantum interference in short phase-
biased superconducting nanowires implementing a superconducting quantum interference proximity
transistor (SQUIPT) that leads to a tunable gap in the wire density of states (DOSs). A quantum-
enhanced turnstile for single electrons based on SQUIPTs has been recently demonstrated exploiting
analogous phenomena [2].
We will show how the flux dependence of the proximity gap induced in the weak link of a SQUIPT can
be exploited as a phase-tunable energy barrier which enables quantum charge configurations with
enhanced functionalities. Coupling two SQUIPTs with a metallic or superconducting Coulomb island
we will present a novel single-electron superconducting transistor (called SQUISET) in which the
charging landscape is coherently driven by an external magnetic field.
Resuming, this device adds new perspectives to quantum electronics being an alternative building
block in fields such as quantum metrology, coherent caloritronics, or quantum information technology.

References:

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Giant acoustic atom: a single quantum system with a deterministic time delay
Guo L. 1,2, Grimsmo A. 3, Frisk Kockum A. 2,4, Pletyukhov M. 3, Johansson G. 2
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Department of Microtechnology and Nanoscience (MC2), Gothenburg, Sweden, 3Université de
Sherbrooke, Institut Quantique and Département de Physique, Sherbrooke, Canada, 4Center for
We investigate the quantum dynamics of a single transmon qubit coupled to surface acoustic waves (SAWs) via two distant connection points. Since the acoustic speed is five orders of magnitude slower than the speed of light, the travelling time between the two connection points needs to be taken into account. Therefore, we treat the transmon qubit as a giant atom with a deterministic time delay. We find that the spontaneous emission of the system, formed by the giant atom and the SAWs between its connection points, initially decays polynomially in the form of pulses instead of a continuous exponential decay behaviour, as would be the case for a small atom. We obtain exact analytical results for the scattering properties of the giant atom up to two-phonon processes by using a diagrammatic approach. We find that two peaks appear in the inelastic (incoherent) power spectrum of the giant atom, a phenomenon which does not exist for a small atom. The time delay also gives rise to novel features in the reflectance, transmittance, and second-order correlation functions of the system. Furthermore, we find the short-time dynamics of the giant atom for arbitrary drive strength by a numerically exact method for open quantum systems with a finite-time-delay feedback loop.

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Electronic transport in semiconductor nanowires and 2D topological insulators
Pribiag V.
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Semiconductors with strong spin-orbit coupling and topological insulators (TIs) have emerged as promising platforms for spintronics and quantum information processing. In the first part of this talk, I will present experiments that rely on the strong spin-orbit interaction in InSb nanowires to achieve all-electrical control of individual electron and hole spins in quantum dots [1, 2]. In the second part of the talk I will present our experimental efforts to demonstrate topological superconductivity in a 2D TI [3]. In proximity to a superconductor, 2D TIs are predicted to host topological superconductivity, which supports non-Abelian excitations known as Majorana zero-modes. We demonstrate that supercurrents can flow through the edge modes of Type-II InAs/GaSb quantum wells, a 2D TI. By gating the devices we observe superconducting transport in all three regimes of the 2D TI: bulk electrons, edge modes and bulk holes. From superconducting quantum interference measurements, we extract the spatial distribution of the supercurrent in all three regimes. A clear transition to edge-dominated supercurrent is observed under conditions of high bulk resistivity. These experiments establish InAs/GaSb as a promising platform for realizing topological superconductivity.

References:
Correlated electron materials under uniaxial stress
Hicks C.W.\textsuperscript{1}, Steppke A.\textsuperscript{1}, Barber M.E.\textsuperscript{1,2}, Park J.\textsuperscript{1}, Mackenzie A.P.\textsuperscript{1,2}
\textsuperscript{1}Max Planck Institute for Chemical Physics of Solids, Dresden, Germany, \textsuperscript{2}University of St Andrews, St Andrews, United Kingdom

Over the past few years we have developed piezoelectric-based apparatus to apply continuously-tunable uniaxial stress to materials, especially at cryogenic temperatures. By preparing samples to have high length-to-width and length-to-thickness aspect ratios, and securing them in place with epoxy, high-elastic-modulus materials such as Sr\textsubscript{2}RuO\textsubscript{4} can be compressed by, so far, at least 1%. Such large strains can induce substantial changes in electronic structure. The superconducting transition temperature of Sr\textsubscript{2}RuO\textsubscript{4} passes through a pronounced peak - it more than doubles - with compression by \textasciitilde0.6%, consistent with driving one of the Fermi surfaces through a topological transition. Compression by \textasciitilde0.3% splits the Néel transition of the heavy-fermion antiferromagnet CeAuSb\textsubscript{2} into two transitions, and further compression suppresses the lower one to zero temperature. In this presentation I will discuss the present state-of-the-art of this technique, and present results of measurements, focusing on the unconventional superconductor Sr\textsubscript{2}RuO\textsubscript{4}.

Currents and phases in quantum rings
Moler K.A.
Stanford University, Stanford, United States

The current that flows in a ring can be a signature of fundamental and topological properties of quantum states of charge-carrying particles. Applying a magnetic flux through a ring creates a phase gradient, in response to which a current flows, creating magnetic fields that we measure with a scanning SQUID microscope. I will take you on a tour of currents and phases in common and exotic quantum materials. Gold rings are normal metals with finite resistance, but remarkably, they carry persistent currents whose sign and magnitude confirm the quantum behavior of disordered metals. Aluminum rings superconduct at low temperatures, and are an ideal model system to study superconducting fluctuations. The strong agreement of theory and experiment in conventional metals and superconductors sets the stage to study superconducting rings interrupted by a single Josephson junction. This geometry allows us to measure a fundamental and informative property of the junction, called the current-phase relation. In junctions made of topological materials, the current could theoretically be 4\pi-periodic rather than 2\pi-periodic as a function of the phase winding in the ring. I will report on progress towards this smoking-gun signature for Majorana modes.
On the superconductivity of FeSe/STO interface

Feng D.
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Recently, interfacial superconductivity up to 75K has been discovered in FeSe/STO and FeSe/BTO interfaces [1,2]. We combine angle resolved photoemission spectroscopy (ARPES), scanning tunneling microscopy (STM) and molecular beam epitaxy (MBE) to study the superconductivity at interfaces and surfaces. Based on the impurity effects and quasiparticle interference behaviors revealed in our STM data, we found that the pairing symmetry of FeSe/STO is the plain \( s \)-wave type [3]. Moreover, with surface electron doping, the FeSe thick film exhibits an anomalous phase diagram with a correlated insulating phase and a superconducting phase with \( T_c \) up to \( \sim 46 \)K [4]. By placing such a heavily electron doped FeSe superconducting layer closer to the FeSe/STO interface, its superconducting gap increases exponentially to the single layer FeSe/STO value [5], which resembles the behavior of the STO phonon strength measured by EELS [6]. Our results demonstrate the critical role of interfacial electron-phonon interactions in the high \( T_c \) of FeSe/STO interface.

I will also briefly introduce our recent STM study of the nematic superconductivity in \( \text{Cu}_x\text{Bi}_2\text{Se}_3 \).

References:

Investigation of grid turbulence decay in He II in a large square channel

Yang J., Ihas G.G.
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Temporal decay of grid turbulence is experimentally studied in superfluid \(^4\)He in a square channel. The second sound attenuation method [1] is used to measure the turbulent vortex line density \( L \) with a novel signal processing technique (phase locked tracking system) to minimize frequency shift effects induced by temperature fluctuations. Grids are pulled at different speeds to generate turbulence at temperatures from 1.5 to 2.1 K. Different power laws for decaying behavior are predicted by theory [2]. According to this theory, \( L \) should decay as \( t^{-11/10} \) when the length scale of energy containing eddies grows from the grid mesh size to the size of the channel. At later time, after the energy containing eddy size becomes comparable to the channel, \( L \) should follow \( t^{-3/2} \). Our recent experimental data exhibit evidence for \( t^{-11/10} \) during the early time and \( t^{-2} \) instead of \( t^{-3/2} \) for later time. Moreover, a consistent bump/plateau feature in between the two decay regimes is prominent and will be discussed.

References:
Dynamics of quasiparticles in Andreev quantum dots

Pothier H., Tosi L., Goffman M., Urbina C.
CEA-Saclay, Quantronics Group, SPEC, Gif-sur-Yvette Cedex, France

In contrast with a bulk superconductor, a single-channel phase-biased superconducting weak link hosts a discrete subgap quasiparticle state, called “Andreev state”. As such, it can be seen as a sort of quantum dot in quasiparticles can be trapped, not due to electrostatic barriers, but to the phase drop. I will present very recent experiments in which, by coupling Andreev quantum dots obtained at one-atom contacts between aluminum electrodes to a microwave resonator (circuit-QED setup) [1], we probe the transitions between states with 0, 1 and 2 quasiparticles.

References:

Field-induced quantum phase transition within a superconducting condensate

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The application of magnetic fields, chemical or hydrostatic pressure to strongly-correlated electron materials can stabilize electronic phases with different organizational principles. We studied Ce0.95Nd0.05CoIn5 where a spin-density wave exists within the superconducting state [1]. We find evidence for a field-induced quantum phase transition that separates two antiferromagnetic phases with identical magnetic symmetry. The zero-field spin-density wave is suppressed at the critical field Hstar=8T, but reemerges at higher fields. The high-field phase shares many properties with the Q phase in CeCoIn5 [2]. Our results suggest that this magnetic instability is not magnetically driven. We propose that it is instead driven by a modification of superconducting condensate at Hstar [3].

References:
Quantum spin fluid behaviors of the kagome- and triangular-lattice antiferromagnets

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The S=1/2 kagome-lattice antiferromagnet is one of interesting frustrated quantum spin systems. The systems exhibit the quantum spin fluid behavior, which was proposed as an origin of the high-Tc superconductivity. The spin gap is an important physical quantity to characterize the spin fluid behavior. Whether the S=1/2 kagome-lattice antiferromagnet is gapless or has a finite spin gap, is still unsolved issue. Because any recently developed numerical calculation methods are not enough to determine it in the thermodynamic limit. Our large-scale numerical diagonalization up to 42-spin clusters and a finite-size scaling analysis indicated that the S=1/2 kagome-lattice antiferromagnet is gapless in the thermodynamic limit[1-3]. It is consistent with the U(1) Dirac spin liquid theory of the kagome-lattice antiferromagnet[4,5]. On the other hand, the density matrix renormalization group calculations supported the gapped Z2 topological spin liquid theory[6,7]. We propose one of better methods to determine whether the spin excitation is gapless or gapped, based on the finite-size scaling analysis of the spin susceptibility calculated by the numerical diagonalization. The present work indicates that the kagome-lattice antiferromagnet is gapless, as well as the triangular-lattice one.

References:

Non-adiabatic geometric phase and decoherence in an open quantum system

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Generalizing the work of Berry, Aharonov and Anandan showed that certain quantum states acquire geometric phases even during non-adiabatic modification of parameters. We analyze how these phases are modified under the influence of dissipative environment. We find dissipative contributions to the acquired phase and modification of dephasing. Analysis is performed for the limiting cases of weak short-correlated noise as well as of slow quasi-stationary noise. Motivated by recent experiments with superconducting quantum bits [1], we find the leading non-adiabatic corrections to the results, known for the adiabatic limit [3].

References:
The elementary excitations of liquid $^3$He: the complete picture unveiled

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We present new results on the dynamics of bulk liquid $^3$He, obtained at very low temperatures using modern inelastic neutron scattering techniques. The data, which cover a very large range in energy and momentum transfer, provide an interesting perspective on the dynamics of this canonical Fermi Liquid. The experimental data confirm the predictions of the Dynamic Many-Body Theory. Furthermore, the comparison to our similar measurements and calculations [1] performed on $^4$He, a Bose Liquid, provides a spectacular illustration of the effects of statistics on the dynamics of many-body quantum systems.

References:

Direct observation of coexisting nematic and superconducting domains in the Ca122 pnictide superconductor under strain

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The Ca122 pnictide is extremely sensitive to strain. Co doping induces superconductivity in this compound at the same point of the phase diagram where antiferromagnetic and orthorhombic order are simultaneously suppressed through a first order phase transition. It has been recently shown that biaxial strain induces a magnetostructural transition and superconductivity in the same sample [1]. Here we make Scanning Tunneling in a sample under biaxial strain and image nanometer sized nematic-orthorhombic and superconducting domains in the same sample [2]. Using atomic size measurements, we characterize electronic properties and spatial distribution of both phases. In the superconducting tetragonal domains we measure the superconducting gap and the vortex lattice and in the orthorhombic domains we observe the nematic band structure through quasiparticle interference measurements. Our work provides first microscopic measurements directly imaging the two different phases at both sides of a quantum critical phase transition.

Finally, I will also present recent advances in the superconductor CaKFe4As4 that shows the highest Tc among stoichiometric pnictide materials (35 K) [3]. I will discuss evidence for two gap superconductivity and show large scale images of the vortex lattice.
References:
* Work supported by Spanish MINECO, ERC Starting Grant and CIG Marie Curie program.

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Coherent manipulation of single atomic-scale two-level defects in amorphous oxides
Lisenfeld J., Bilmes A., Weiss G., Ustinov A.
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In structurally disordered solids, some atoms or small groups of atoms are able to quantum mechanically tunnel between two nearly equivalent sites. These atomic tunneling systems have been previously identified as the cause of various low-temperature anomalies of bulk glasses and as a source of decoherence of superconducting quantum circuits where they are sparsely present in the disordered oxide barriers. A tiny mechanical deformation of the oxide barrier changes the energies of the atomic tunneling systems. We have measured these changes by tracing changes in the microwave spectra of superconducting qubits induced by coherent interactions with microscopic two-level tunneling systems. The observed hyperbolic dependence of the energy splitting of individual atomic tunneling states on external strain [1], for the first time, confirmed the central hypothesis of the two-level tunneling model for disordered solids [2]. Tuning the properties of individual defects by applying mechanical strain allowed us to detect their mutual interactions [3] and study their spectral properties [4]. Recently, we also probed the interaction between individual two-level defects and quasiparticles in a superconductor and observed an increase of defect decoherence rates with quasiparticle density.

References:

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Fermi surface topology and chirality in Weyl semimetals
Arnold E.1, Naumann M.1, Wu S.-C.1, Sun Y.1, Ajeesh M.O.1, dos Reis R.D.1, Shekhar C.1, Kumar N.1, Süß V.1, Schmidt M.1, Nicklas M.1, Felser C.1, Yan B.1, Hassinger E.1,2
The non-centrosymmetric monopnoctides are a new class of materials, which are putative Weyl semimetals [1]. In these semimetals three-dimensional chiral massless quasiparticles, the so-called Weyl fermions [2], arise at symmetry protected linear band crossings and are predicted to induce novel quantum mechanical phenomena such as the chiral anomaly and topological surface states [3-5].

Here we present an overview over the Fermi surface topologies of two members of this family, TaP [6] and TaAs [7]. Based on quantum oscillation measurements and ab-initio bandstructure calculation, we will show that TaAs contains chiral Weyl Fermi surface pockets, which coexist with topologically trivial electron and hole pockets. Its sister compound TaP, however, only contains topologically trivial Fermi surface pockets. Thus the observed negative magnetoresistances in TaP, which was initially interpreted as a sign for the chiral anomaly is reevaluated in terms of inhomogeniouse current distributions in the samples [8].

References:
The unconventional superconductivity in URhGe, which develops within the ferromagnetic state is considered to be of the spin-triplet type mediated by the longitudinal spin fluctuations [1]. This notion is further supported by the observation of the re-entrant superconductivity in the magnetic field of 12T [2]. Here we present the first direct microscopic measurements of the magnetic fluctuations in URhGe, which establish the energy scale and the wavevector dependence of the magnetic fluctuations, which tests the predictions of the theory [3]. Our cold inelastic neutron scattering in high magnetic fields probed the critical fluctuations associated with the Curie temperature, which is gradually suppressed by the magnetic field. The inelastic measurements showed a suppression of the transverse fluctuations at fields up to 11T, close to the onset of the re-entrant superconductivity. The small-angle neutron scattering (SANS) measured both the transverse and longitudinal magnetic fluctuations. SANS showed a quick suppression of the fluctuations already in small fields around 1T and showed no longitudinal fluctuations, seemingly at odds with the recent NMR observation of the longitudinal fluctuations in Co doped URhGe[4].

References:
Calorimetry is an important tool in investigating thermodynamics. Especially for a small system in mesoscopic level, fast and sensitive calorimeters which are able to measure energy transferred within the system is in great request. Recently it has been proposed that one could also couple the calorimeter to a quantum system, for instance, to a superconducting qubit. The calorimeter can then be used to observe the exchange of microwave photons [1]. Works have been done before on fast and sensitive calorimeter [2-4]. To enhance the energy resolution of calorimeter, heat conductance and heat capacity of the absorber of calorimeter are needed to be low [5]. Here we show the measurement results of the heat conductance and heat capacity of normal metal with hysteretic Josephson junctions. We found anomalously high heat capacity of Au, Ag and Cu at low temperature, and the value measured for the three metals are about one order of magnitude higher than that calculated from the standard free electron model. We have replaced the normal metal with InAs semiconductor nanowires. Compared with metal, the heat conductance and heat capacity of semiconductor nanowire are expected to be low due to low electron density, so higher energy resolution is expected for the an InAs based calorimeter.

References:

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Superfluid phases for a model of $^3$He confined in nematic aerogels[1]

Wiman J., Sauls J.A.
Northwestern University, Physics & Astronomy, Evanston, United States

Superfluid $^3$He has recently been observed in disordered `nematic aerogel` (N-aerogel) materials.[2] The N-aerogels consist of 9 nm diameter strands that are predominantly oriented along one axis, producing far more anisotropy in confinement than could be achieved in previous experiments using anisotropic silica aerogels. In one class of N-aerogels, Dmitriev et al. reported the first observation of the superfluid Polar phase, a phase which is stabilized by uniaxial anisotropy and not present in pure bulk $^3$He. The strong nematic order and small radius of the strands suggest that they may be modeled as arrays of parallel line impurities. We show that the experimentally determined phase diagram, including Polar, polar-distorted A, and polar-distorted B phases, for this class of N-aerogels is well accounted for by strong-coupling Ginzburg-Landau theory with a regular array of such line impurities. We also find that the locations of these phase transitions are insensitive to positional disorder of the impurities.

References:
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Gapless Fermi-surface spin liquid on the kagome lattice and its instabilities
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Quantum kagome antiferromagnets (QKA’s) are spin systems in which strong frustration coupled with quantum fluctuations suppresses any long-range order. In its stead a new state of matter, a quantum spin liquid with long-range entanglement but no long-range order, arises. The properties of this state are hotly debated with several competing theoretical proposals [1].

One of the few experimental realization of a QKA is Zn-brochantite, ZnCu$_3$(OH)$_6$SO$_4$ [2]. In this compound we observe two distinct spin-liquid regimes, a high-temperature one, preceded by quantum-critical behavior at even higher temperatures, and a low-temperature one with an enhanced density of states [3].

We show that site-mixing impurities, unavoidable in most QKA candidates, are strongly coupled to the low-temperature spin liquid state in Zn-brochantite [4]. Their behavior identifies the low-temperature state of Zn-brochantite as a gapless spinon Fermi-surface spin liquid [4,5].

We also observe a field-induced instability of this spin liquid, most likely due to spinon pairing, where a (possibly nodal) gap opens up [6]. We thus obtain a comprehensive understanding of the spin-liquid state and its instabilities in the QKA Zn-brochantite, which can serve as a benchmark against which to compare theoretical proposals.

References:
realized a model experiment of “classical decoherence”, on which we quantitatively separated mechanical damping and dephasing processes [5]. It was found that the latter depends non-trivially on the magnitude of frequency fluctuations. These results were extended to the situation encountered when one nanomechanical mode far from equilibrium is coupled dispersively through geometric nonlinearities to another mode driven by a force field [6]. Pushing the study a step forward, we developed a sensitive frequency tracking technique relying on nanomechanical bifurcation to unravel a motion-dependent frequency noise, which origin remains controversial [7].

References:

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15.20-15.40
Congress Hall

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Identifying detrimental effects for multiband superconductivity - application to Sr$_2$RuO$_4$
Ramires A.$^1$, Sigrist M.$^2$
$^1$ETH, Institute for Theoretical Studies, Zurich, Switzerland, $^2$ETH, Institute for Theoretical Physics, Zurich, Switzerland

We propose a general scheme to probe the compatibility of arbitrary pairing states with a given normal state Hamiltonian by the introduction of a concept called superconducting fitness. This quantity gives a direct measure of the suppression of the superconducting critical temperature in the presence of key symmetry-breaking fields. A merit of the superconducting fitness is that it can be used as a tool to identify nontrivial mechanisms to suppress superconductivity under various external influences, in particular, magnetic fields or distortions, even in complex multiorbital systems. In the light of this concept we analyze the multiband superconductor Sr$_2$RuO$_4$ and propose a new mechanism for the suppression of superconductivity in multiorbital systems, which we call interorbital effect, as a possible explanation for the unusual limiting feature observed in the upper critical field of this material.

References:

Tuesday, 15 August 2017
15.20-15.40
H1

187
Pure $^3$He in nematic aerogel
Dmitriev V.$^1$, Soldatov A.$^{1,2}$, Yudin A.$^1$

$^1$ETH, Institute for Theoretical Studies, Zurich, Switzerland, $^2$ETH, Institute for Theoretical Physics, Zurich, Switzerland
A new superfluid phase of $^3$He - the polar phase - is realized in high-density nematic aerogel (nafen) [1]. Nafen consists of strands which are nearly parallel to one another. It leads to an anisotropic scattering of $^3$He quasiparticles that makes the polar phase favorable [2]. In experiments [1] the strands of nafen were covered by $\approx 2.5$ atomic layers of $^4$He. In presence of such a coverage the scattering conserves spin and should be specular at low pressures and diffusive above $\sim 25$ bar [3,4]. Here we report results of NMR studies of pure $^3$He in nafen. In this case the strands are covered by $\sim 2$ atomic layers of paramagnetic solid $^3$He and the scattering should be diffusive at all pressures. In addition, due to a fast exchange between liquid and solid $^3$He atoms a magnetic scattering channel appears. The experiments were done in a wide range of pressures with samples of different porosities. It was found that the polar phase is no longer observed at all pressures and $^3$He superfluid transition temperatures are significantly suppressed in comparison with the case of $^4$He coverage. Our results show that the magnetic scattering plays a decisive role in the observed changes of the superfluid phase diagram. Additional experiments with smaller $^4$He coverages confirm this assumption.

References:
In general a superconducting state breaks multiple symmetries and, therefore, is characterized by several different coherence lengths $\xi_i, i=1,\ldots,N$. Moreover in multiband material even superconducting states that break only a single symmetry are nonetheless described, under certain conditions by multi-component theories with multiple coherence lengths. As a result of that there can appear a "type-1.5" state where some coherence lengths are smaller and some are larger than the magnetic field penetration length $\lambda$. One of the properties of this regime is that vortices can attract one another at long range but repel at shorter ranges. Such a system can form vortex clusters in low magnetic fields. I will discuss the recent experimental evidence that this regime is realized in Sr$_2$RuO$_4$, providing evidence for a multicomponent order parameter. Also I will discuss that it is consistent with other previously observed effects in this material such as "zero-creep" in the absence of dramatic increase of critical current.

References:


Type-1.5 superconductivity in multicomponent systems
E Babaev, J Carlström, M Silaev, JM SpeightPhysica C: Superconductivity and its Applications 533, 20-35
**190**

**Spin-dependent thermoelectric effects in superconductor-ferromagnet tunnel junctions**

Kolenda S., Wolf M.J., Fischer G., Sürgers C., Beckmann D.

Karlsruhe Institute of Technology, Institute of Nanotechnology, Karlsruhe, Germany, Karlsruhe Institute of Technology, Physikalisches Institut, Karlsruhe, Germany

We report on the experimental observation of spin-dependent thermoelectric effects in superconductor-ferromagnet tunnel junctions in high magnetic fields. The thermoelectric signals are due to a spin-dependent lifting of particle-hole symmetry on the energy scale of the superconducting gap. Our results directly prove the coupling of spin and heat transport in superconductors with spin splitting of the density of states. A Seebeck coefficient of about -100 µV/K is obtained from our data. The thermoelectric effects can be further increased by an exchange field induced via the proximity effect with the ferromagnetic insulator europium sulfide.

**References:**


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**Quantum oscillations from a bulk Fermi surface in Kondo insulating SmB$_6$**


University of Cambridge, Cambridge, United Kingdom, National High Magnetic Field Laboratory, Tallahassee, United States, National High Magnetic Field Laboratory, Los Alamos, United Kingdom, National Academy of Sciences of Ukraine, Kiev, Ukraine

Our recent observation of quantum oscillations in the Kondo insulator SmB$_6$ has revealed a bulk Fermi surface consisting of large ellipsoidal spheres characteristic of metallic hexaborides [1]. I will discuss new magnetic torque measurements of the angular dependence of the quantum oscillations, and their absolute size that provide further support for the picture of a bulk three-dimensional Fermi surface of neutral low energy excitations.

**References:**

Odd-frequency cooper pairing in normal liquid $^3$He at aerogel interface
Mizuhata H.\textsuperscript{1}, Nomura N.\textsuperscript{1}, Kimura Y.\textsuperscript{1,2}, Obara K.\textsuperscript{1}, Yano H.\textsuperscript{1}, Ishikawa O.\textsuperscript{1}
\textsuperscript{1}Osaka City University, Graduate School of Science, Osaka, Japan, \textsuperscript{2}University of Tokyo, Institute for Solid State Physics, Tokyo, Japan

A novel feature of condensate state in liquid $^3$He is predicted theoretically, which consists of odd-frequency spin triplet s-wave Cooper pairs as a proximity effect\textsuperscript{1}. Such an s-wave state will appear inside aerogel near the interface contacting with superfluid $^3$He-B. The aerogel plays a role of impurity in quasiparticles scattering for the appearance of odd frequency Cooper pairings. It is expected that this novel state will cause an enhancement of magnetization at lower temperatures\textsuperscript{2,3}. We actually observed such an enhancement of magnetization near the edge of aerogel, where we coated aerogel strands with 2.5 layers of $^4$He films in advance\textsuperscript{4}. However, we also observed an enhancement of magnetization inside aerogel. This indicates that the observed enhancement near the edge of aerogel may partly include the enhancement of magnetization caused by surface solid $^3$He on aerogel. Now we have coated aerogel with 3.0 layers of $^4$He films to kill solid $^3$He. We have measured magnetization as a function of temperature. We discuss whether there still exists the surface solid $^3$He on aerogel by coating $^4$He or not. Also, we discuss whether this novel state shows an enhancement of magnetization at lower temperatures.

References:

On-chip nuclear demagnetisation cooling of electrons in a nanoelectronic device
Jones A.T.\textsuperscript{1}, Bradley D.I.\textsuperscript{1}, Guénault A.M.\textsuperscript{1}, Gunnarsson D.\textsuperscript{2,3}, Haley R.P.\textsuperscript{1}, Holt S.\textsuperscript{1}, Pashkin Y.A.\textsuperscript{1}, Penttilä J.\textsuperscript{4}, Prance J.R.\textsuperscript{1}, Prunnila M.\textsuperscript{2}, Roschier L.\textsuperscript{3,4}
\textsuperscript{1}Lancaster University, Department of Physics, Lancaster, United Kingdom, \textsuperscript{2}VTT Technical Research Centre of Finland Ltd, Espoo, Finland, \textsuperscript{3}Bluefors Cryogenics Oy, Helsinki, Finland, \textsuperscript{4}Aivon Oy, Helsinki, Finland

We describe a new technique\textsuperscript{1} for the cooling of electrons in a nanostructure: nuclear demagnetisation of on-chip, thin-film copper refrigerant. We are motivated by the potential improvement in the operation of nanoelectronic devices below 10 mK. At these temperatures, weak electron-phonon coupling provides a bottleneck to traditional cooling, yet here gives the advantage of thermal isolation between the environment and the on-chip electrons, enabling cooling significantly below the base temperature of the host lattice. To demonstrate this we electroplate copper on to the metallic islands of a Coulomb blockade thermometer (CBT), and hence provide a direct thermal link between the cooled copper nuclei and the device electrons. The CBT can provide primary thermometry of its low internal electron temperature [2], and we use this to monitor the cooling process. Using an optimised demagnetisation profile we observe the electrons being cooled from 9 mK to 4.5 mK, and remaining below 5 mK for an experimentally useful time of 1200 seconds. We anticipate that applying this technique with higher initial magnetic fields and lower initial temperatures will yield sub-1mK electron temperatures.
Tuesday, 15 August 2017
09.15-10.00
Congress Hall

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$^3$He in aerogel - discovery and some historic experiments

Parpia J.
Cornell University, Department of Physics, Ithaca, United States

I will provide a brief overview of experimental investigations of $^3$He in aerogel starting from the first observations at Cornell and Northwestern through experiments in the many laboratories that conducted investigations worldwide on this system. The talk will focus on historic context from the use of aerogel to introduce isotropic disorder through a brief discussion of the use of anisotropic aerogel to demonstrate control over new phases of $^3$He.

Tuesday, 15 August 2017
10.00-10.45
Congress Hall

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Superfluid phases of liquid $^3$He in random media and confined space

Sauls J.
Northwestern University, Physics, Evanston, United States

The quantum liquid phases of $^3$He confined in random solids and sub-micron structures provide a unique system for studying the struggle between spontaneous symmetry breaking by a BCS condensate, and disorder originating from atomic-scale impurities to bulk and surface random potentials. This competition leads to a remarkable spectrum of phases exhibiting broken spin- and orbital rotation symmetries, as well as discrete space-time symmetries, that are not realized in pure liquid $^3$He. I will highlight theoretical ideas and understanding of the effects of disorder on unconventional BCS condensates that have emerged from studies of the superfluid phases of liquid $^3$He in random media and confined geometries.

References:
Supported by U.S. National Science Foundation Grant DMR-150873.
Superfluid $^3$He with globally anisotropic quenched disorder

Halperin W.
Northwestern University, Evanston, United States

In 1995 disordered phases of superfluid $^3$He in highly porous silica aerogel were discovered by Porto and Parpia at Cornell University using torsional oscillator techniques, and from NMR observations by Sprague, Haard, Kycia, Rand, Lee, and Halperin at Northwestern University. Also at Northwestern University, Thuneberg, Yip, Fogelström and Sauls developed a theoretical framework that guided both the experiment and theory that followed in 30 different research groups and institutions worldwide. The interplay of length scales, those intrinsic to the pure superfluid on the one hand, and from the silica aerogel structure on the other, are responsible for the existence of new quantum states of matter with sharply-defined thermodynamic transitions. The order parameter symmetry of these superfluid phases is controlled by engineering globally-uniform anisotropy in the aerogel.

Topologically protected Bogoliubov Fermi surfaces

Agterberg D.F.$^1$, Brydon P.M.R.$^2$, Timm C.$^3$

$^1$University of Wisconsin, Milwaukee, United States, $^2$University of Otago, Dunedin, New Zealand, $^3$Technische Universität Dresden, Dresden, Germany

It is commonly believed that, in the absence of disorder or an external magnetic field, there are three possible types of superconducting excitation gaps: The gap is nodeless, it has point nodes, or it has line nodes. Here, we show that, for an even-parity nodal superconducting state which spontaneously breaks time-reversal symmetry, the low-energy excitation spectrum generally does not belong to any of these categories; instead, it has extended Bogoliubov Fermi surfaces [1]. These Fermi surfaces are topologically protected from being gapped by a $\mathbb{Z}_2$ invariant. We also show that superconducting states possessing these Fermi surfaces are energetically stable. A crucial ingredient in our theory is that more than one band is involved in the pairing; since all candidate materials for even-parity superconductivity with broken time-reversal symmetry are multiband systems, we expect these $\mathbb{Z}_2$-protected Fermi surfaces to be ubiquitous.

References:

Mesoscopic transport experiments with cold atoms

Brantut J.-P.
EPFL, Institute of Physics, Lausanne, Switzerland
Over the last decade, the level of control over cold atomic gases has improved to the point that atoms can now be used to simulate the behavior of electrons in realistic materials. I will present the progresses that we accomplished in the last years in measuring the transport properties of cold atomic gases using the Landauer two-terminals setup. I will present the first observation of quantized conductance for neutral particles [1]. Its evolution as attractive interactions between particles is increased up to unitarity will be presented as pairing and superfluidity emerge [2,3]. I will then describe the most recent technical developments, namely the transposition of scanning gate microscopy in the cold atoms context, and the observation of quantum interferences in transport.

References:
Observation of high pressure phase in Shastry-Sutherland Model Substance SrCu$_2$(BO$_3$)$_2$ by high pressure THz ESR

Ohta H.¹, Sakurai T.², Hijii K.¹, Okubo S.¹, Uwatoko Y.³, Kudo K.⁴, Koike Y.⁵

¹Kobe University, Molecular Photoscience Research Center, Kobe, Japan, ²Kobe University, Research Facility Center for Science and Technology, Kobe, Japan, ³University of Tokyo, Institute for Solid State Physics, Kashiwa, Japan, ⁴Okayama University, Department of Physics, Okayama, Japan, ⁵Tohoku University, Department of Applied Physics, Sendai, Japan

SrCu$_2$(BO$_3$)$_2$, which shows multi-step magnetization plateaus at low temperature, has attracted much attention since the discovery by Kageyama et al. [1]. It is a unique 2 dimensional orthogonal dimer antiferromagnet with the singlet ground state and a spin gap, and Miyahara et al. suggested that it is equivalent to the Shastry-Sutherland Model [2]. Moreover, as the ratio $\alpha = J'/J$, where $J'$ and $J$ are inter-dimer and intra-dimer exchange interactions, respectively, is 0.64 for SrCu$_2$(BO$_3$)$_2$ and it is close to the critical ratio $\alpha_c = 0.677$ between the dimer and the plaquette phases suggested by the theory [3], various pressure measurements have been performed to find the pressure induced phase transition [4-6]. However, the experimental results are still controversial. Therefore, we have developed a new hybrid-type pressure cell for our high pressure THz ESR and extended our pressure from 1 GPa [6] to 2.5 GPa [7] and applied to SrCu$_2$(BO$_3$)$_2$ single crystal. As THz ESR at 2 K can observe the spin gap directly, we have clearly shown that the spin gap still exists at 2 GPa. This is in contrary to the previous suggestion that the spin gap disappears at 2GPa by the X-ray measurement under high pressure [4]. Moreover, our results suggest the pressure induced phase transition at 1.85 GPa.

References:

Quantum dynamics in superconductor - quantum dot junctions

van Zanten D.M.T.¹, Basko D.², Khaymovich I.², Pekola J.³, Courtois H.¹, Winkelmann C.B.¹

¹Université Grenoble Alpes, Institut Néel, Grenoble, France, ²Université Grenoble Alpes, LPMMC, Grenoble, France, ³Aalto University, Helsinki, Finland

We report on the realization of a single-electron source, where current is transported through a single-level quantum dot tunnel coupled to two superconducting leads (S) [1,2]. The quantum dot is provided by a colloidal gold nanoparticle, about 5 nm in diameter. When driven with an ac gate voltage at frequency $f$, the experiment demonstrates electron turnstile operation, delivering a current $I = e f$. Compared to the more conventional superconductor-normal-metal-superconductor turnstile [3], our superconductor-quantum-dot- superconductor device presents a number of novel properties, including higher immunity to the unavoidable presence of nonequilibrium quasiparticles in superconducting...
leads. Further, we demonstrate its ability to deliver electrons with a very narrow energy distribution. Finally, we discuss signatures of an intriguing effect going beyond the semi-classical picture, associated to the quantum dynamics at the anti-crossing between the quantum dot level and the superconducting gap edge [4].

References:
We report on combined measurements of heat and charge transport through a single-electron transistor [1]. The device acts as a heat switch actuated by the voltage applied on the gate. The Wiedemann-Franz law for the ratio of heat and charge conductances is found to be systematically violated away from the charge degeneracy points. The observed deviation agrees well with the theoretical expectation [2]. With large temperature drop between the source and drain, the heat current away from degeneracy deviates from the standard quadratic dependence in the two temperatures.

References:

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14.50-15.20
H1

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New phases of superfluid $^3$He in nematic aerogel

Dmitriev V., Soldatov A., Yudin A.

P.I. Kapitza Institute for Physical Problems of RAS, Moscow, Russian Federation, Moscow Institute of Physics and Technology, Dolgoprudny, Russian Federation

Superfluid phase diagram of $^3$He confined in nematic aerogel (which strands are nearly parallel to one another) qualitatively differs from the diagrams of bulk $^3$He or $^3$He in nearly isotropic silica aerogel. A strong global anisotropy of nematic aerogel suppresses various possible superfluid phases of $^3$He differently, and instead of A and B phases 3 new phases become favorable: the polar phase, the polar-distorted A phase, and the polar-distorted B phase. NMR experiments which have allowed to identify these phases and investigate their properties will be described in the talk. Possible future experiments will be also discussed.

Tuesday, 15 August 2017
14.50-15.20
Congress Hall

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High-spin superconductivity in topological half-Heusler semimetal YPtBi

Paglione J.
In all known fermionic superfluids, Cooper pairs are composed of spin-1/2 quasi-particles that pair to form either spin-singlet or spin-triplet bound states. The "spin" of a Bloch electron, however, is fixed by the symmetries of the crystal and the atomic orbitals from which it is derived, and in some cases can behave as if it were a spin-3/2 particle. The superconducting state of such a system allows pairing states to form "beyond triplet", with higher spin quasi-particles combining to form quintet or even septet pairs. After reviewing the general properties of Pt- and Pd-based half-Heusler systems, I will present evidence for the first experimentally realized case of a high-spin fermionic superfluid in the exotic superconducting state of the half-Heusler compound YPtBi, as well as the rich landscape of ground states and intertwining orders found in the X-Y-Z family of materials.

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G2

206
Magnetostriction-driven ground-state in hexagonal perovskites

The magnetic ground state of Sr₃ARuO₆, with A = (Li,Na), is studied using neutron diffraction, resonant x-ray scattering, and laboratory characterisation measurements of high-quality crystals. Combining these results allows us to observe the onset of long-range magnetic order and distinguish the symmetrically allowed magnetic models, identifying in-plane antiferromagnetic moments and a small ferromagnetic component along the c-axis. While the existence of magnetic domains masks the particular in-plane direction of the moments, it has been possible to elucidate the ground state using symmetry considerations. We find that due to the lack of local anisotropy, antisymmetric exchange interactions control the magnetic order, first through structural distortions that couple to in-plane antiferromagnetic moments and second through a high-order magnetoelastic coupling that lifts the degeneracy of the in-plane moments. The symmetry considerations used to rationalise the magnetic ground state are very general and will apply to many systems in this family, such as Ga₃ARuO₆, with A = (Li,Na), and Ga₃LiOsO₆ whose magnetic ground states are still not completely understood.
Sr₃LiRuO₆ Structure

References:
Quantum spin liquids

Balents L.
University of California Santa Barbara, Kavli Institute of Theoretical Physics, Santa Barbara, United States

Quantum spin liquids[1,2] may be considered “quantum disordered” ground states of spin systems, in which zero point fluctuations are so strong that they prevent conventional magnetic long range order. More interestingly, quantum spin liquids are prototypical examples of ground states with massive many-body entanglement, of a degree sufficient to render these states distinct phases of matter. Their highly entangled nature imbibes quantum spin liquids with unique physical aspects, such as non-local excitations, topological properties, and more. I will discuss the different types of quantum spin liquids, the models and theories used to describe them, and describe the current status of experiments.

References:

Order parameter symmetry in $^3$He and UPt$_3$

Halperin W.
Northwestern University, Evanston, United States

New anisotropic states of superfluid $^3$He have been studied at Northwestern University similar to those in a number of superconducting compounds, like UPt$_3$ and Sr$_2$RuO$_4$. I will discuss and compare three unconventional superconducting materials for which measurements of physical properties indicate unusual order parameter symmetry including chiral symmetry and broken time reversal symmetry, most clearly in evidence in high quality single crystals of UPt$_3$, pure superfluid $^3$He, and superfluid $^3$He in highly porous silica aerogel. These systems have multiple thermodynamic phases, with different order parameter structure. Theoretical predictions indicate that anisotropic quasiparticle scattering favors the stability of anisotropic quantum states. In particular we have shown this is the case for chiral states of superfluid $^3$He confined to uniformly anisotropic silica aerogel. This also appears to be the case for superconducting UPt$_3$ and can be attributed to an inhomogeneous impurity phase associated with prism plane stacking faults.
Superconducting detectors and sub-Kelvin instrumentation for astronomy

Monfardini A.
CNRS, Inst NEEL, Grenoble, France

Astronomy is historically the main driver for developing new detectors. The ultimate search of sensitivity, strict requirement for most astronomical applications, ends up inexorably in lowering the temperature of the sensing part until reaching almost the absolute zero. In fact the thermal noise "hides" the tiny amounts of energy that we try to resolve. Moreover, these small amounts of energy can only be measured adopting even smaller "units" like individual excitations in superconductors (quasi-particles) or ultra-low temperature phonons.

It is also thanks to the efforts deployed by the low temperature physics community if the state-of-the-art today shows multi-thousands pixels, i.e. large field-of-view, cameras operating at IR-to-radio frequencies and unveiling the details of the cold and primordial Universe.

After a general introduction, I will mainly focus, as a case study, on our own NIKA2 (New IRAM KID Arrays 2) millimetre-wave imager/polarimeter operating at the 30-meters radiotelescope at Pico Veleta. NIKA2, based on Kinetic Inductance Detectors (KID), is today the biggest mm-wave camera available to the astronomers for general purpose observations, ranging from the local Universe to cosmological distances. General context will be given.

References:

Multi-terminal Josephson junctions as topological matter

Meyer J.S.
Universite Grenoble Alpes, INAC/PHELIQS, Grenoble, France

Topological phases of matter have attracted much interest in recent years. Starting with gapped phases such as topological insulators and superconductors, more recently gapless topological phases possessing topologically protected band crossings have been discovered.

Here we show that n-terminal Josephson junctions with conventional superconductors may provide a straightforward realization of tunable topological materials in n−1 dimensions [1], the independent superconducting phases playing the role of quasi-momenta.

In particular, we find zero-energy Weyl points in the Andreev bound state spectrum of 4-terminal junctions. The topological properties of the junction may be probed experimentally by measuring the transconductance between two voltage-biased leads [2], which we predict to be quantized.

Further, the analogy between the spectrum of Andreev bound states in an n-terminal Josphepsjon junction and the bandstructure of an n-1-dimensional material opens the possibility of realizing topological phases in higher dimensions, not accessible in real materials.

References:
Transition Edge Sensors (TES) are a powerful tool for the detection of electromagnetic radiation from microwaves through gamma rays. TES arrays have been used in a wide range of applications such as astronomy, particle astrophysics, nuclear security, and materials analysis in the laboratory and at light source facilities. These measurements have been enabled by the sensitivity provided by superconducting detectors and by the readout of multi-kilopixel detector arrays by superconducting multiplexer technology. At this talk, I will focus on two applications: probing cosmology using superconducting polarimeters and probing biology, chemistry and materials with a new soft x-ray TES spectrometer at Stanford Synchrotron Radiation Lightsource (SSRL).

Quantum mechanics continues to stretch the limits of human thought by asserting that objects can exist simultaneously in multiple states until they are projected into a familiar classical outcome by a measurement - hence a cat in a sealed box can be dead and alive until the lid is opened. Moreover, two objects can be entangled such that a probe of one automatically yields information about the other, even if they are at opposite ends of the universe. Generating entanglement in bulk at the macroscopic scale is the engine behind the second quantum revolution, promising ultra-secure communications systems and unparalleled computing power. At a yet larger cosmic scale, this same entanglement which once troubled the architect of the theory of general relativity, Einstein, is now postulated to be the thread that stitches the fabric of the universe. Cryogenic superconducting resonant circuits and detectors, originally developed in the 1970s and 80s, form the basis of contemporary quantum information processing hardware when operated at the level of single excitation quanta in a well-controlled electromagnetic environment. In this talk, I will illustrate the essential features of quantum measurement and entanglement as observed with superconducting qubits.
Superconductivity and cryogenics for future circular colliders

Benedikt M.
CERN, Geneva, Switzerland

The global Future Circular Collider (FCC) study is designing a 100-TeV hadron collider (FCC-hh) in a new 100 km long tunnel, i.e. about four times larger than the operating Large Hadron Collider (LHC). The FCC study also includes the design of a high-luminosity electron-positron collider (FCC-ee), which could be installed in the same tunnel as a potential first step as well as an energy upgrade of the LHC using the FCC-hh technology (HE-LHC). The scope of the FCC study comprises accelerators, technology, infrastructure, detectors, physics, international governance models, and implementation scenarios.

Key technologies for FCC are beyond-state-of-the-art 16 T dipole magnets, based on some 6000 tons of advanced NbSn superconductor, as well as highly efficient superconducting radiofrequency systems for all collider scenarios. Use of HTS and MgB2 cables is also considered for special magnets, SC links and other applications. All these technologies and applications also require large cryogenic plants and distribution systems. The presentation will summarize how a large-scale future research infrastructure like a high-energy circular collider makes use of advances in superconductivity and cryogenics.

Chiral 1D transport in magnetic topological insulators: precise quantization and manipulation

Goldhaber-Gordon D.1,2, Fox E.1,2, Rosen I.2,3, Yang Y.4, Jones G.4, Elmquist R.4, Kou X.5, Pan L.6, Wang K.6
1Stanford University, Physics, Stanford, United States, 2SLAC National Accelerator Laboratory, Menlo Park, United States, 3Stanford University, Applied Physics, Stanford, United States, 4National Institute of Standards and Technology, Gaithersburg, United States, 5Shanghai Tech University, Shanghai, China, 6UCLA, Los Angeles, United States

Chiral (one-way) one-dimensional conduction is important for metrology, and could be interesting technologically. Such conduction occurs at the edge of a 2D electron system in high magnetic field, giving rise to dissipationless longitudinal transport and Hall conductance well-quantized in multiples of the von Klitzing constant: the quantum Hall effect. The recent prediction and discovery of the quantum anomalous Hall (QAH) effect in thin films of the three-dimensional ferromagnetic topological insulator CrxBl2Sb1-x-yTe3 has opened new possibilities for chiral edge state-based devices in zero external magnetic field. Like the nu=1 quantum Hall system, the QAH system is predicted to have a single chiral edge mode encircling the boundary of the film, with a chirality determined by the TI's out-of-plane magnetization. Backscattering of the chiral edge mode should be suppressed, and this is supported by earlier measurements. We will report on new observations of well-quantized Hall
resistivities along with very low longitudinal resistivities. We will also demonstrate 1D conduction not only at film edges but also along engineered magnetic domain walls within the plane.

Friday, 11 August 2017
17.15-18.00
G3

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Levitons: a unique single charge quantum excitation for electron quantum optics and flying qubits
Glattli D.C., Roulleau P.
CEA - Saclay, SPEC, Gif-sur-Yvette, France

Single electron sources have made possible a real Electron Quantum Optics and have enable the use of single charges propagating in ballistic channels as flying charge qubits. The ideal electron source is provided by levitons [1,2]. They are minimal excitation states carrying integer charge and produced by voltage pulses on a contact. Observations of Hong Ou Mandel interference of single or doubly charged indistinguishable levitons show 100% HOM dip resulting from the Fermi statistics [1] and an exceptional robustness of HOM correlations versus temperature is observed. Using quantum noise measurements the quantum state tomography of leviton wavepackets have been performed [3], an important step for electron quantum optics. Beyond periodic leviton injection we will consider the pseudo-random binary sequence of levitons showing new features in the HOM correlation [4]. Finally, the possibility to generate levitons in the Quantum Hall regime, where chirality can be exploited for electron quantum optics, and the generation of on-demand anyon with fractional charge [5] will be discussed.

References:

Friday, 11 August 2017
11.00-11.30
G1

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Influence of surface bound states on damping of MEMS oscillator in superfluid $^3$He-B
Lee Y.$^1$, Zheng P.$^1$, Jiang W.G.$^1$, Barquist C.S.$^1$, Chan H.B.$^2$
$^1$University of Florida, Department of Physics, Gainesville, United States, $^2$The Hong Kong University of Science and Technology, Department of Physics, Clear Water Bay, Kowloon, Hong Kong

The mechanical properties of a micro-electro-mechanical oscillator with a gap of 1.25 μm was studied in superfluid $^3$He-B at various pressures. The damping of the shear mode of the oscillator was measured in the linear and nonlinear damping regimes. The quality factor of the oscillator remains low ($Q \approx 80$) down to 0.1T$_c$, many orders of magnitude less than the intrinsic quality factor, exhibiting a dominant linear temperature dependence in the low temperature limit [1]. The oscillator enters into a
nonlinear regime above a certain threshold velocity. The damping increases rapidly in the nonlinear region and eventually prevents the velocity of the oscillator from increasing beyond the critical velocity which is much lower than the Landau critical velocity [2]. We propose a multiple scattering mechanism of the surface Andreev bound states to be a possible cause for the anomalous behavior.

References:

Monday, 14 August 2017
14.00-14.30
H1

217
Quantum engineering of superconducting qubits

Oliver W.1,2

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Superconducting qubits are coherent artificial atoms assembled from electrical circuit elements and microwave optical components. Their lithographic scalability, compatibility with microwave control, and operability at nanosecond time scales all converge to make the superconducting qubit a highly attractive candidate for the constituent logical elements of a quantum information processor. In this talk, we revisit the design, fabrication, and control of the superconducting flux qubit. By adding a high-Q capacitor, we dramatically improve its reproducibility, anharmonicity, and coherence, achieving T1 = 55 us and T2 = 90 us. We identify quasiparticles as a leading cause of temporal variability in the T1. We introduce and demonstrate a stochastic control technique that effectively pumps away these quasiparticles and thereby stabilizes and improves T1.

References:

Friday, 11 August 2017
09.45-10.30
G3

218
Quantum oscillations and superconductivity in the cuprate high Tc’s

Sebastien S.

I will discuss measurements of quantum oscillations and electrical transport in the cuprate high temperature superconductors to explore the high magnetic field state in these materials.

Saturday, 12 August 2017
09.45-10.30
The quantum critical point of cuprate superconductors

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Cuprates exhibit exceptionally strong superconductivity, with critical temperatures and magnetic fields that can exceed 100 K and 100 T, respectively. However, the nature of the electron interactions responsible for the strong pairing is still not clear.

I will present recent experimental studies performed using high magnetic fields to suppress superconductivity and access the non-superconducting ground state of cuprates in the $T = 0$ limit. These reveal the presence of a quantum critical point in the phase diagram of cuprates [1,2], where the enigmatic pseudogap phase ends, around which the superconducting phase forms a dome, and at which the resistivity exhibits an anomalous linear dependence on temperature [3,4].

Strong similarities with the quantum critical point at which antiferromagnetic order ends in organic [5], iron-based [6] and heavy-fermion [7] superconductors suggest that antiferromagnetic spin correlations also play a fundamental role in cuprates, in particular as the mechanism for $d$-wave pairing. The outstanding questions are: Does antiferromagnetic order extend up to the critical point in cuprates? Is long-range order necessary to open a (pseudo)gap and generate anomalous, non-Fermi-liquid scattering and mass renormalization down to $T \sim 0$?

References:
use a triple GaAs quantum dot to manipulate exchange coupling between a spin-1/2 qubit and a singlet-triplet qubit and apply it for QND readout of the spin-1/2 state as well as CPHASE operation. We prepare phase-controlled singlet-triplet entanglement in two of the three dots and show the singlet-triplet phase evolution frequency is modulated depending on the orientation of the spin-1/2 in the third dot. This frequency modulation can be used for QND measurement of the spin-1/2 qubit and also for CPHASE operation of the singlet-triplet qubit. Finally, I will discuss quantum dephasing in either qubit due to the nuclear spin environment. I show that the dephasing is significantly reduced by decreasing the data acquisition time in the non-ergodic condition of the magnetic noise and also that the qubit gate fidelity is largely improved by adaptive feedback control to compensate for the magnetic noise in real time.

Friday, 11 August 2017
12.10-12.30
G3

222
Anisotropic Pauli spin-blockade effects in double quantum dots made from InAs nanowire
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Semiconductor quantum dots (QDs) are one of the most promising building blocks for the physical implementation of electron-spin based quantum computers.1,2 The electron spin relaxation time in the QD is essential for robust and functional computations but limited by two dominating mechanisms: nuclear hyperfine3 and spin-orbit interactions4. The former is usually random, while the latter is anisotropic. Experimentally, the magnitude of leakage current through double quantum dot (DQD) in spin-blockade regime reflects the strength of spin mixing.

In this work, we investigate the spin mixing effects caused by hyperfine interaction and spin-orbit interaction in a top-finger-gate defined DQD in InAs nanowire, as shown in Fig. 1. In spin-blockade regime, by detuning the energy levels of each dot and applying an external magnetic field, we systematically study the roles of two spin-mixing mechanisms and identify each mechanism. Spin mixing arising from hyperfine interaction can be suppressed completely by a magnetic field of several mili-Tesla. By applying the external magnetic field in different directions with regard to the nanowire axis, the anisotropic lifting of the Pauli spin blockade is observed and attributed to the anisotropic spin-orbit interaction.
Quantum simulation of a Fermi-Hubbard model using a semiconductor quantum dot array

Hensgens T.¹, Fujita T.¹, Janssen L.¹, Li X.², Van Diepen S.³, Reichl C.⁴, Wegscheider W.⁴, Das Sarma S.⁵, Vandersypen L.M.K.⁶

¹Delft University of Technology, QuTech & Kavli Institute of Nanoscience, Delft, Netherlands, ²University of Maryland, Condensed Matter Theory Center & Joint Quantum Institute, College Park, United States, ³Netherlands Organization for Applied Scientific Research (TNO), Delft, Netherlands, ⁴ETH Zürich, Zürich, Switzerland

Seminal efforts are underway to study novel emergent magnetic and electronic properties of strongly-correlated electronic phases of low-dimensional condensed matter physics using dedicated quantum simulators. Experimentally realized correlations, however, are typically limited by the residual entropy of the initialized systems, and scaling to similarly homogeneous but larger system sizes is not always straightforward.

We show that quantum dot arrays in semiconductors constitute a promising platform in these regards. Not only do tunnel-coupled dots readily adhere to the Fermi-Hubbard model in the effective low temperature limit necessary for seeing strong correlations, but one can also directly leverage developments for using quantum dots as spin qubits. By describing an experimental toolbox for Hamiltonian engineering, validated by direct numerical simulations, we negate the combination of disorder inherent to the solid state and the inefficiency of calibration routines which has previously
limited the scaling of quantum dot experiments in scope and size. As we map out the experimental phase space of a triple quantum dot device [1], we show the onset of collective Coulomb blockade [2], the finite-size analogue of the interaction-driven Mott transition.

References:

Tuesday, 15 August 2017
11.30-12.30
Congress Hall

224
Majorana wires and next steps toward topological quantum devices
Marcus C.
Station Q Copenhagen and Center for Quantum Devices, Niels Bohr Institute, University of Copenhagen DK

This talk will briefly review the experimental status and evidence for Majorana modes in semiconductor-superconductor nanowire systems, then discuss extensions to future topological devices, and how we are assembling components for topological information processing. Along the way, new materials challenges arise, including moving from as-grown hybrid nanowires to top-down processed 1D systems fabricated from two-dimensional heterostructures. Many new problems, from fundamentals of how to identify Majorana zero modes, to how to process and store quantum information with topological protection, to how to design and extended hybrid superconductor-semiconductor materials will be touched on, though the most exciting developments are for the future. Research supported by the Danish National Research Foundation and Microsoft Corporation.

Tuesday, 15 August 2017
15.40-16.00
G1

225
Fully coupled dynamics of two-fluid model in thermal counterflow: deformation of the Poiseuille normal fluid profile
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Since the proposal of the two-fluid model in 1941 by Tisza and Landau, the model has succeeded in revealing many kinds of physics on superfluidity. Since the rotation of superfluid is sustained only by quantized vortices, the vortex filament model (VFM) has been used for superfluid 4He and worked very much. Most previous numerical studies of the VFM in thermal counterflow were performed for the periodic boundary condition under the prescribed normal fluid profile [1]. However, the recent visualization experiments observed the deformation of the normal fluid profile in a square channel [2], which invites us to study the fully coupled dynamics of two-fluid in a channel. This motivation is closely related to the old problem on the two-stage transition toward turbulence too [3]. Thus we study numerically the fully coupled dynamics of two-fluid model in thermal counterflow in a square channel. The superfluid and the normal fluid are treated by the VFM and the Navier-Stokes equation.
respectively, and they are coupled by mutual friction. We found the profile of the normal fluid can change from the Poiseuille flow to the tail-flattened flow[2]. We discuss the mechanism of the deformation.

References:

Wednesday, 16 August 2017
09.00-10.00
Congress Hall

226
High temperature conventional superconductivity
Eremets M.
Max-Planck-Institut fur Chemie, Mainz, Germany

Progress in conventional phonon-mediated superconductivity will be discussed, in particular, the record 203 K critical temperature $T_c$ in sulfur hydride at high pressures [1]. This superconductivity has been proved by observation of zero resistance, Meissner effect [2], isotope effect, X-ray diffraction studies [3], in infrared [4] and Raman studies. Other hydrides also revealed superconductivity with $T_c > 100$ K [5]. The mechanism of this apparently conventional superconductivity was elucidated in numerous theoretical works. In particular, it turned out that hydrogen atoms give the major input (~90%) into the superconductivity, and in this respect, sulfur hydride can be considered as atomic metallic hydrogen. Recent results on pure hydrogen at pressures up to 480 GPa also will be presented. Prospects for achieving high critical temperatures of superconducting transition at ambient pressure will be discussed too.

References:

Thursday, 10 August 2017
11.30-11.50
G2

227
Defects in low dimensional quantum magnets
Povarov K.1, Simutis G.1, Schmidiger D.1, Galeski S.1, Gvasaliya S.1, Mansson M.1, Chernyshev A.2, Mohan A.3, Singh S.3, Hess C.3, Buchner B.3,4, Savici A.5, Kolesnikov A.5, Ollivier J.6, Piovano A.6, Perring T.7, Bewley R.7, Guidi T.7, Zaliznyak I.8, Zheludev A.1
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