Dynamic Quantum Matter

NORDITA

KTH VETENSKAP OCH KONST

STOCKHOLMS UNIVERSITET

Stockholm, Sweden

December 10 – 13, 2018

Organizers:

A.V. Balatsky**, NORDITA,**
J. Bardarson, **KTH Royal Institute of Technology**
Annica Black-Schaffer, **Uppsala University**
J.T. Haraldsen**, University of North Florida**
J. Hellsvik, **Nordita and KTH Royal Institute of Technology**
P. Hofmann, **Aarhus University**
J. Weissenrieder, **KTH Royal Institute of Technology**

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Nordic Institute for Theoretical Physics,

KTH Royal Institute of Technology,

and

Stockholm University

Introduction

Over the past century, the starting point in nearly any new study of condensed matter have been Fermi liquid theory and the associated Landau-Ginzburg-Wilson approach to phase transitions, supplemented with important concepts including localization and classification according to symmetry. These ideas are based on the fundamental notion of an ordered state characterized by a Landau order parameter and the emergence of quasiparticles corresponding to the broken symmetry that can often be approximated as non-interacting. This paradigm has been remarkably successful, with prominent examples being BCS theory of superconductivity and Fermi liquid theory.

The conventional approaches for treating condensed matter described above have recently been challenged by two developments. The first is the growing library of states that do not display classic Fermi liquid behavior or conventional Landau orders, e.g., topological and non-local orders that go beyond the Landau-Ginzburg-Wilson approach. The second is that many materials exist on the verge of transitions to different types of ordered states. Competing orders and interactions lead to entanglement and fluctuations that span more than one “typical” kind of excitation. As a result, the conventional notion of well-defined quasiparticles no longer applies.

These developments are encapsulated within the new category of condensed matter known as “quantum materials”, which has stimulated a host of new ideas based on unconventional correlated, entangled, and topological orders. Importantly, entangled orders, where the description of one order is incomplete without specifying its entangled counterpart, are purely quantum in nature and thus inherent to these materials. These materials have been challenging to understand and model with traditional approaches, but also offer great potential for new functionalities (e.g. using multiferroic materials for low power sensing) tuned by varying external conditions (e.g., temperature and doping).

One reason our understanding of quantum matter remains limited is because conventional theoretical and experimental approaches typically operate near equilibrium. In contrast, the microscopic features (e.g., correlations, entanglement, time dependent like odd frequency pairing and topology) that determine the properties of quantum materials naturally reveal themselves in the time domain, since their temporal evolution is governed by the full Hamiltonian, which contains interactions. These interactions determine transient correlations and coherences in quantum materials. An intrinsic time dependence can also strongly influence the symmetries of ordered states and lead to formation of dynamic orders, as e.g. found in odd-frequency superconducting systems.

Closely accompanying theory and modeling developments, we see a rapid rise of new probes of matter, most prominently, MAX IV and ESS, which are capable of revealing a new and exciting behavior of quantum matter at the short time scale with high spatial resolution. This makes this topic highly timely from a very broad condensed matter perspective. In a broader context, similar developments impact research on classical matter. To stimulate the exchange of ideas between classical and quantum matter research we will also have lectures on the dynamic classical matter. Moreover, quantum materials hold a promise as an important expansion of the class of materials for sensors used in a search for dark matter, which further unite this topic with other contemporary physics pursuits. We will therefore have lectures dedicated to the potential impact of quantum materials in the search for dark matter.

Location: Nordita

Scope:
- Entangled and competing orders
- Dynamic multiferroicity and coupled critical points
- Dynamic orders and time orders
- Transient dynamics and correlations
- Dynamics of hidden orders
- Discoveries of classical active matter
- Dynamics of classical and quantum fluids
- Hidden and odd frequency orders

Contents

Workshop Schedule

Monday, December 10

8:30 a.m. – Registration – NORDITA Bldg. @ Roslagstullsbacken 23

Session I (Chair: A. Balatsky)

9:00 – 9:15 a.m. – Opening Remarks: A. Balatsky and J. Hellsvik

9:15 – 10:00 a.m. – Z.X. Shen

10:00 – 10:45 a.m. – M. Wallin

10:45 – 11:30 a.m. – Coffee Break

11:30 – 12:00 a.m. – A. Pertsova

12:00 – 12:30 p.m. – Y. Kedem

12:30 – 2:00 p.m. – Lunch – AlbaNova University Center

Session II (Chair: A. Black-Shaffer)

2:00 – 2:45 p.m. – B. Trauzettel

2.45 – 3:30 p.m. – V. Tzwiller

3:30 – 4:00 p.m. – Coffee Break

4:00 – 5:00 p.m. – Round Table Discussion

5:00 – 8:00 p.m. – Welcome reception

Tuesday, December 11

Session III (Chair: O. Tjernberg)

9:00 – 9:45 a.m. – J.T. Haraldsen

9:45 – 10:30 a.m. – P. Hofmann

10:30 – 11:15 a.m. – Coffee Break

11:15 – 11:45 a.m. – D. Clogherty

11:45 – 12:15 p.m. – K. Dunnett

12:15 – 2:00 p.m. – Lunch – AlbaNova University Center

Session IV (Chair: B. Trauzettel)

2:00 – 2:45 p.m. – A. Black-Shaffer

2.45 – 3:30 p.m. – F. Parhizgar

3:30 – 4:00 p.m. – Coffee Break

4:00 – 5:00 p.m. – Round Table Discussion

Wednesday, December 12

Session V (Chair: J. Bardarson)

9:00 – 9:45 a.m. – P. Coleman

9:45 – 10:30 a.m. – A. Balatsky

10:30 – 11:15 a.m. – Coffee Break

11:15 – 12:00 p.m. – S. Bonetti

12:00 – 12:45 p.m. – Ch. Rüegg

12:30 – 2:00 p.m. – Lunch – AlbaNova University Center

Session VI (Chair: J. Hellsvik)

2:00 – 2:45 p.m. – J. Wettlaufer

2.45 – 3:30 p.m. – C. Verdozzi

3:30 – 4:00 p.m. – Coffee Break

4:00 – 5:00 p.m. – Round Table Discussion

6:00 – 9.00 p.m. – Workshop dinner, Albanova

Thursday, December 13

KTH Materials Dialogue Day

Oskar Klein, AlbaNova Universitetscentrum, Roslagstullsbacken 21, Stockholm

See Schedule on

https://www.kth.se/en/forskning/forskningsplattformar/material/dialogue-day-2018/program-1.854988

2:00 – 2:30 p.m. – T. Kimura

2.30 – 3:00 p.m. – J. Mentink

3:15 – 4:15 p.m. – A Imamoglu (Alba Nova Colloquium) - Oscar Klein Auditorium

Invited and Contributed Talks

Invited Talks

Alexander Balatsky – Dynamic Orders in Superconductors and Dirac Matter
Nordic Institute for Theoretical Physics, Sweden

Dynamics of quantum matter is an exciting and promising direction to investigate novel quantum coherences. There are generally at least two complementary notions of quantum dynamics and order in time: a) dynamic orders that are natural extensions of the concept of orders we have at equilibrium: e.g. superconducting or density wave orders in driven systems. This view is supported by recent exciting observations of the coherent states at higher temperatures in optically pumped materials. I will illustrate this approach in driven Dirac Materials; b) the dynamic orders that do not have a conventional "equal time" or equilibrium analog. One example often quoted here is the time crystals. I will discuss the odd-frequency (Berezinski) pairing as an example of novel order in time domain that is complementary to time crystals.

Annica Black-Schaffer – Odd-frequency superconductivity in Sr2RuO4 and UPt3 measured by Kerr effect
Uppsala University, Sweden

In this talk I will show that essentially all multi-band superconductors host bulk odd-frequency superconductivity. Applying these results to the chiral topological superconductor Sr2RuO4, we find that an intrinsic Kerr effect is direct evidence for this odd-frequency state. We use both general two- and three-orbital models, as well as a realistic tight-binding description of Sr2RuO4 to demonstrate that odd-frequency pairing arises due to finite hybridization between different orbitals in the normal state, and is further enhanced by finite inter-orbital pairing. If time permits, I will also show how a similar bulk odd-frequency superconducting state appears in UPt3.

Stefano Bonetti - Terahertz-Driven Phonon Upconversion in $SrTiO_3$
Stockholm University, Sweden

Direct manipulation of the atomic lattice using intense long-wavelength laser pulses has become a viable approach to create new states of matter in complex materials. Conventionally, a high frequency vibrational mode is driven resonantly by a mid-infrared laser pulse and the lattice structure is modified through indirect coupling of this infrared-active phonon to other, lower frequency lattice modulations. Here, we drive the lowest frequency optical phonon in the prototypical transition metal oxide SrTiO3 well into the anharmonic regime with an intense terahertz field. We show that it is possible to transfer energy to higher frequency phonon modes through nonlinear coupling. Our observations are carried out by directly mapping the lattice response to the coherent drive field with femtosecond x-ray pulses, enabling direct visualization of the atomic displacements.

Piers Coleman - The Continued Challenge of Heavy Fermion Superconductors: Candidates for Composite, Hidden and Odd frequency order.
Rutgers University, USA

The low transition temperature and high tunability of heavy electron materials make them an ideal test bed for exploring new forms of order and superconductivity. I will discuss the challenges posed by various heavy electron materials, in their normal, quantum critical and superconducting configurations, not only questions they pose, but the lessons they might impart for other higher temperature superconductors. In particular, we'll examine the case of the 115 superconductors, with Tc's ranging from 0.2 to 20K, which in their most extreme form undergo a direct transition from Curie paramagnet to Superconductor, indicating that the local moments directly entangle with the condensate to form "composite pairs". I'll present a simple mean-field theory of this kind of behavior[1]. Another interesting and unsolved challenge is posed by the hidden order heavy fermion superconductors, including URu2Si2 and the cubic systems UBe13 and its closely related rare earth cousins PrT2Al20 (T=Ti, V), the latter which appear to involve a competition of quadrupole order and superconductivity. There is strong indication that each of these systems involves valence fluctuations
between Kramers and non-Kramers doublets, with the possibility of new kinds of order, such as hastatic order. Finally, I'll end discussing failed superconductivity, and the fascinating possibility that the topological Kondo insulator SmB6 may involve a nearby

competing phase with a neutral Fermi surface that is best understood as a failed odd-frequency superconductor.

1. "Composite pairing in a mixed valent two channel Anderson model", R. Flint, A. Nevidomskyy and P. Coleman, Phys. Rev. B. 84, 064514 (2011).
2. Hastatic Order in URu2Si2: Hybridization with a Twist, Premala Chandra, Piers Coleman and Rebecca Flint, Phys. Rev. B 91, 205103 (2015).
3. Skyrme insulators: insulators at the brink of superconductivity, Onur Erten, Po-Yao Chang, Piers Coleman, Alexei M. Tsvelik, Phys. Rev. Lett., 119, 057603 (2017).

Jason T. Haraldsen - Magnetic Dirac bosons in the spin dynamics of a Kagome lattice

University of North Florida, USA

Dirac bosons provide a magnetic analog to the standard Dirac fermions and can provide insight into the dynamics of both systems. Using linear spin-wave theory, we examine the magnetic Dirac bosons in the spin dynamics of the Kagome lattice. After an examination of the Dirac bosons in a honeycomb lattice, we analyze the effects of a 3-SL system and show the symmetries produce dispersionless flat bands that are due to the localized geometry in the ferromagnetic Kagome lattice. Furthermore, we show that the antiferromagnetic systems produce similar Dirac boson, which is different that honeycomb lattice.

Philip Hofmann - Electronic structure and electron dynamics in two-dimensional dirac materials

University of Aarhus, Denmark

Artificial two-dimensional (2D) materials, such as graphene or single-layer transition metal dichalcogenides (TMDCs), permit the realization of massless and massive Dirac fermions. A special feature of the 2D materials is that their electronic properties, for instance their band gap, can be strongly influenced by either their dielectric environment or by the excited carrier density in the material. Using time- and angle-resolved photoemission spectroscopy, we here exploit this to achieve a dynamic change in the electronic properties of 2D materials, exploring both 2D semiconductors (single layer WS2) and metals (single layer TaS2). We also address the possibility to address the valley degree of freedom in single layer and bilayer TMDCs.

Atac Imamoglu - Physics with atomically thin mirrors

Institute of Quantum Electronics, Switzerland

Transition metal dichalcogenide (TMD) monolayers, such as molybdenum diselenide (MoSe2), represent a new class of semiconductors exhibiting novel features such as strong Coulomb interactions and efficient light-matter coupling. These two features together with fast improvement of sample quality ensured the demonstration of an atomically thin mirror. More generally, van der Waals heterostructures, composed of such atomically thin semiconducting mirrors, graphene, ferromagnetic CrI3 and insulating boron nitride, constitute a rich playground for investigation of many body physics and realization of novel device concepts.

Tsuyoshi Kimura - Magnetoelectric effect in visible light range due to ferroic order of magnetoelectric-active multipole moments

University of Tokyo, Kashiwa, Japan
E-mail: tkimura@edu.k.u-tokyo.ac.jp

The magnetoelectric (ME) effect is a cross-coupling phenomenon between electricity and magnetism, in which electric polarization (magnetization) is induced by a static magnetic field (electric field). The optical magnetoelectric (OME) effect is an extension of the ME effect to the frequency region, that is, the ME effect induced by an oscillating electric or magnetic field of electromagnetic wave. From the symmetry point of view, both the space-inversion and time-reversal symmetries must be broken for the presence of the linear (O)ME effect which can cause nonreciprocal light propagation. In this presentation, we deal with ME active multipole moments which break both the time reversal and the space inversion and result in ME activity as well as nonreciprocal light propagation. Examples of such multipole moments are magnetic toroidal and magnetic quadrupole moments. We introduce our strategy of how to embed such multipole moments in materials and show our study on the OME effects in visible light range due to ferroic order of these multipole moments.

This work was done in collaboration with K. Kimura (U. Tokyo), T. Katsuyoshi (U. Tokyo), Y. Yamaguchi (Osaka U.), Y. Araya (Osaka U.), Y. Sawada (Osaka U.), S. Kimura (Tohoku U.), and T. Arima (Univ. of Tokyo).

Johan Mentink – Simulating ultrafast quantum magnetism with machine learning

Radboud University, Nijmegen

The explosive growth of digital data and its related energy consumption is pushing the need to develop fundamentally new physical principles for faster and more energy-efficient control of materials. Ultimately, the best compromise between speed and energy-efficiency is realized by employing coherent quantum dynamics. However, such dynamics is usually restricted to isolated systems temperatures far below room temperature which strongly limits application perspectives. Here we present our efforts towards finding alternative scenarios to control and magnetic materials in the quantum regime at room temperature. Instead of controlling magnetism with magnetic fields or spin-polarized currents, we focus on the ultrafast control of exchange interactions as we recently established for Mott-Hubbard systems [1]. In particular, we show that short time-dependent electric fields can not only enhance and reduce the effective exchange interaction, but for strong electric fields even change the sign, as was recently confirmed in cold atom experiments [2]. Moreover, focusing on Heisenberg antiferromagnets, we show that ultrashort perturbations of exchange interactions triggers a time-dependent superposition of magnon pairs. We argue that this is a manifestation magnon entanglement and can be efficiently described by magnon-pair operators [3]. Furthermore, since the dynamics is governed by the energy of the exchange interactions it can be observed even at room temperature. Finally, we present our very first steps towards studying this magnon entanglement in the non-linear regime. To this end we apply the recently developed neural quantum states [4] to the dynamics of the 2D quantum Heisenberg model. We find excellent agreement for small systems where the dynamics is still accessible with exact diagonalization. Moreover, for large systems and for small perturbations, close correspondence with interacting spin-wave theory and rapid convergence with the number of neural network parameters is found [5]. This paves the way to explore the strongly nonequilibrium regime, with potentially enables the discovery of ultrafast reversal of magnetic order down to the quantum limit.

1. Mentink, J.H., Manipulating magnetism by ultrafast control of the exchange interaction. J. Phys.: Condens. Matter, 2017. 29 p. 453001
2. Görg, F., et al., Enhancement and sign change of magnetic correlations in a driven quantum many-body system. Nature, 2018. 553: p. 481.

3. Bossini, D., et al., Laser-driven quantum magnonics and THz dynamics of the order parameter in antiferromagnets. arXiv:1710.03143, 2017.
4. Carleo, G. and M. Troyer, Solving the quantum many-body problem with artificial neural networks. Science, 2017. 355(6325): p. 602.
5. G. Fabiani and J.H. Mentink, Investigating ultrafast quantum spin dynamics with machine learning. In preparation, 2018.

Anna Pertsova - Transient many-body instability in driven Dirac materials
Royal Institute of Technology, and Stockholm University, Sweden

The defining feature of a Dirac material (DM) is the presence of nodes in the low-energy excitation spectrum leading to a strong energy dependence of the density of states (DOS). The vanishing of the DOS at the nodal point implies a very low effective coupling constant which leads to stability of the node against electron-electron interactions. Non-equilibrium or driven DM, in which the DOS and hence the effective coupling can be controlled by external drive, offer a new platform for investigating collective instabilities. In this work, we discuss the possibility of realizing transient collective states in driven DMs. Motivated by pump-probe experiments which demonstrate the existence of long-lived photo-excited states in DMs, we consider an example of a transient excitonic instability in an optically-pumped DM. Specifically, we consider a pumping scheme which generates non-equilibrium chemical potentials for electrons and holes. Such pumping combined with Dirac nature of quasiparticles create favorable conditions for excitonic instability. We consider several important examples of DMs such as single-layer graphene, three-dimensional topological insulators and Dirac and Weyl semimetals. We propose signatures of the transient excitonic condensate that could be probed by scanning tunneling spectroscopy, photoemission and optical measurements. We also provide estimates of critical temperatures and lifetimes of transient excitonic states.

Christian Rüegg - TBA
Paul-Scherrer Institute, Switzerland

Zhi-Xun Shen - Time domain measurements of quantum materials
Stanford University, USA

Björn Trauzettel - Detection and characterization of many-body localization in central spin models
University of Würzburg, Germany

We analyze a disordered central spin model, where a central spin interacts equally with each spin in a periodic one-dimensional (1D) random-field Heisenberg chain. If the Heisenberg chain is initially in the many-body localized (MBL) phase, we find that the coupling to the central spin suffices to delocalize the chain for a substantial range of coupling strengths. We calculate the phase diagram of the model and identify the phase boundary between the MBL and ergodic phase. Within the localized phase, the central spin significantly enhances the rate of the logarithmic entanglement growth and its saturation value. We attribute the increase in entanglement entropy to a nonextensive enhancement of magnetization fluctuations induced by the central spin. Finally, we demonstrate that correlation functions of the central spin can be utilized to distinguish between MBL and ergodic phases of the 1D chain. Hence, we propose the use of a central spin as a possible experimental probe to identify the MBL phase.

Mats Wallin - Vortices and hidden disorder
KTH Royal Institute of Technology, Sweden

Current problems in single photon detection, topological materials and complex order pose questions about the interplay between collective excitations and features of the substrate. I will talk about aspects and examples of such phenomena. Single vortex excitations in a superconducting film are considered near a KT transition and display unusual properties. I also discuss some signatures of importance of substrate structure from some recent simulations.

John Wettlaufer - Messages from the Soft Side
NORDITA, Sweden and Yale University, USA

Val Zwiller - Generation, manipulation and detection of quantum states of light at the nanoscale

KTH Royal Institute of Technology, Sweden

With the aim of realizing complex quantum networks, we develop quantum devices based on nanostructures to generate quantum states of light with semiconductor quantum dots, single photon detectors based on superconducting nanowires and on-chip circuits based on waveguides to manipulate light. The generation of single photons can readily be performed with single quantum dots. We demonstrate a very high single photon purity exceeding 99.99% generated at 795 nm with GaAs quantum dots [1], these quantum emitters also allow for interfacing with atomic ensembles. To enable long distance communication, we are also developing devices based on single InAs quantum dots able to emit at telecom frequencies [2]. To allow for complex architectures, on-chip integration is desirable. We will demonstrate filtering and routing of single photons with tunable ring resonators on a chip and discuss the scalability of this approach [3]. Generation and manipulation of quantum states of light would be useless without single photon detectors. We are therefore developing high-performance single photon detectors based on superconducting nanowires and will present state-of-the-art performance in terms of detection efficiency and time resolution [4].

1. L. Schweickert et al., On-demand solid-state single-photon source with 99.99% purity, Appl. Phys. Lett. 112, 093106 (2018).
2. K. D. Zeuner et al., A stable wavelength-tunable triggered source of single photons and cascaded photon pairs at the telecom C-band, Appl. Phys. Lett. Accepted (2018).
3. A. W. Elshaari et al., On-chip single photon filtering and multiplexing in hybrid quantum photonic circuits, Nat. Commun. 8, 379 (2017).
4. I. Esmaeil Zadeh et al., Single-photon detectors combining ultra-high efficiency, detection-rates, and timing resolution, APL Photonics 2, 111301 (2017).

Contributing Talks

Dennis Clougherty - Infrared Problem in Cold Atom Adsorption on 2D Materials
University of Vermont, USA

Kirsty Dunnett - Intrinsic dynamic multiferroicity of a ferroelectric quantum critical point
Nordita, Sweden

Dynamical multiferroicity, where fluctuations of electric dipoles lead to magnetisation, is an example of where two coexisting orders are impossible to disentangle. We calculate the magnetic susceptibility near the ferroelectric quantum critical point (FE QCP) and find a region with enhanced magnetic signatures that appears near the FE QCP, and is controlled by the tuning parameter of the ferroelectric phase. We thus suggest that any ferroelectric quantum critical point may be an *inherent* multiferroic quantum critical point. The effect is small but observable - we suggest the quantum paraelectric strontium titanate as a candidate material where the magnitude of the induced magnetic moments can be ~5 $10^{-7}\mu_B$ per unit cell near the FE QCP.

Yeron Kedem - Superconductivity at low doping: New pairing mechanism driven by critical ferroelectric modes
Stockholm University, Sweden

Superconductivity at low doping is a long-standing enigma. The standard theoretical framework, BCS theory and its extensions, cannot be applied to this regime, but nonetheless, the phenomenon was observed experimentally. I will present a new electrons pairing mechanism, mediated by ferroelectric modes, that is valid in this regime. The transition between para- and ferroelectricity, at zero temperature, is related to a quantum critical point, and this give unique characteristics to the spectrum of the modes, creating a so-called soft mode. The result is analytical solutions for the superconducting order parameter, with peculiar properties related to the quantum critical nature of the pairing. The state would yield unusual experimental observations: (i) A gap function that is non-monotonic in temperature (ii) Superconductivity occurring in an insulator.

Fariborz Parhizgar – Large Josephson current in Weyl nodal loop semimetals due to odd-frequency superconductivity
Uppsala University, Sweden

In this talk, I will present our results of the effect of odd-frequency pairing on the proximity induced superconductivity in Weyl nodal loop materials (WNL). [1] These materials have fully spin-polarized surface states which naively is expected to prevent conventional superconductivity due to its spin-singlet nature.

By sandwiching a WNL between two conventional superconductors we theoretically showed that the pairing can be transformed from spin-singlet pairs into odd-frequency spin-triplet in the WNL. This together with large density of states on the surfaces leads to very large Josephson current, even up to orders of magnitude larger than for normal metals. As a result, WNL Josephson junctions offer unique possibilities for detecting and exploring odd-frequency superconductivity.

Claudio Verdozzi - Merging NEGF and Ehrenfest dynamics for electronic charge-transfer, molecular motors, and skyrmion dynamics
Lund University, Sweden

We use nonequilibrium Green's functions (NEGF) coupled to the Ehrenfest Dynamics (EA) to investigate i) donor-acceptor complexes ii) molecular motors in quantum transport setups and iii) classical skyrmions dynamics.

For donor-acceptor complexes, we show that ultrafast charge separation driven by correlations can in principle occur in organic nanoscale systems, but it will only be correctly predicted by theoretical treatments that include time-nonlocal correlations. For molecular motors, we use the adiabatic limit of the NEGF combined with the EA to obtain the current-induced forces on the nuclei. Correlations can change dramatically the physical scenario by e.g. introducing a sizeable damping in the self-sustained van der Pol-like oscillations due to positive electronic friction. Finally, we briefly show how EA and NEGF can be used used to describe the steering of classical skyrmions via currents.

List of Participants

First Name	Last Name	Affiliation	Location	Participation
Shubham	Agarwal	Oulu University	Oulu, Finland	Speaker
Alexander	Balatsky	NORDITA	Stockholm, Sweden	Organizer/Speaker
Jens	Bardarson	KTH Royal Institute of Technology	Stockholm, Sweden	Organizer
Annica	Black-Schaffer	Uppsala University	Uppsala, Sweden	Organizer
Stefano	Bonetti	Stockholm University	Stockholm, Sweden	Speaker
Adrien	Bouhon	NORDITA	Stockholm, Sweden	Participant
Dennis	Clougherty	University of Vermont	Vermont, USA	Participant
Piers	Coleman	Rutgers University	New Jersey, USA	Speaker
Roberto	Diaz Perez	NORDITA	Stockholm, Sweden	Participant
Kristy	Dunnett	NORDITA	Stockholm, Sweden	Participant
Paramita	Dutta	Uppsala University	Uppsala, Sweden	Participant
Hossein	Ehteshami	KTH Royal Institute of Technology	Stockholm, Sweden	Speaker
Oscar	Grånäs	Uppsala University	Uppsala, Sweden	Participant
Jason T.	Haraldsen	University of North Florida	Florida, USA	Organizer
Johan	Hellsvik	KTH Royal Institute of Technology	Stockholm, Sweden	Organizer
Philip	Hofmann	Aarhus University	Aarhus, Denmark	Organizer/Speaker
Atac	Imamoglu	Institute of Quantum Electronics	Zurich, Switzerland	Speaker
Diana	Iusan	Uppsala University	Uppsala, Sweden	Participant
Qingdong	Jiang	NORDITA	Stockholm, Sweden	Participant

Yaron	Kedem	Stockholm University	Stockholm, Sweden	Participant
Tsuyoshi	Kimura	University of Tokyo	Kashiwa, Japan	Speaker
Floriana	Lombardi	Chalmer University of Technology	Goteborg, Sweden	Participant
Mahdi	Mashkoori	Uppsala University	Uppsala, Sweden	Participant
Johan	Mentink	Radboud University	Nijmegen, Netherlands	Speaker
Fariborz	Parhizgar	Uppsala University	Uppsala, Sweden	Participant
Anna	Pertsova	NORDITA	Stockholm, Sweden	Speaker
Marisa	Pons	University of the Basque Country	Bilbao, Spain	Participant
Jonathon	Riddell	McMaster University	Hamilton, Canada	Participant
Christian	Rüegg	Paul Scherrer Institute	Villigen, Switzerland	Speaker
Zhixun	Shen	Stanford University	California, USA	Speaker
Andreas	Theiler	Uppsala University	Uppsala, Sweden	Participant
Oscar	Tjernberg	KTH Royal Institute of Technology	Stockholm, Sweden	Participant
Bjoem	Trauzettel	University of Wuerzberg	Wuerzberg, Germany	Speaker
Claudio	Verdozzi	Lund University	Lund, Sweden	Participant
David	Vergara	University of Mexico	Mexico City, Mexico	Participant
Mats	Wallin	KTH Royal Institute of Technology	Stockholm, Sweden	Speaker
Jonas	Weisenrieder	KTH Royal Institute of Technology	Stockholm, Sweden	Organizer
John	Wettlaufer	KTH Royal Institute of Technology	Stockholm, Sweden	Speaker
Val	Zwiller	KTH Royal Institute of Technology	Stockholm, Sweden	Speaker

Break Time Puzzles

Keep your brain going!

Dynamic Quantum Matter Word Searches

Find these words in the puzzles!

BOSON COMPUTATION DIRAC EXCITATIONS EXPERIMENT FERMION GRAPHENE
HERMITIAN HONEYCOMB LANDAU MAGNETISM MATERIALS PLASMONICS QUANTUM
SEMIMETAL SYMMETRY THEORY TOPOLOGICAL TRANSPORT WEYL

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V Z R W R E E E M F J Q F G C B H B R K G M S R P H Y M A V G W M Y Z E G R G F
U M E X R A W U F U F D S P A J L F R B P G F M N L E K S Z J N S M X K M P M V
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A W K J B S A F F B F N H B O S O N P J J D I O Z Y E I X T J D T N Y C J O V P
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U Z U Z O X L H X T T X V A B N T I P H O O G O X B E G H D M U A J Z A K E Y I
C K J T A N Q O G C L U W R T Y H R U O I W D G F H T G W Q W D M Z G G I O M U
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Y P B O E F C O I E C M Y Y R X W Y U N G L U G C Z D M V Q T H W P B D E E C I
B K R T L H T T Z G V E L E O E I I U U Q D H T Y Z R H N X F Z S P K P K N J B
E L R H L O A Q X G O N R V O W P V J B G E Q R G Y N Q G V A A E L Y B W F O H
N Y H R A T G Y I B N T X J K I G G G O E Q O L T W N X R L P D W H C S G A O H
R Q L V U P Z I F E Q R V O C T S Y C K T Y Y V B R D E A S C D T E B G T S G L
T Y A P A X A H C S E M I M E T A L X F P I P X N C H H P G F B V E D Q I K O B
J Q M Z U I N R E A B S T W N H Q Q Y W R R V M Y P Y P H N I M D V T O D F U F
G O X U D W E C D E L N A I T I M R E H P X O T X G Z D E R K N X O L T U R A J
C D H O A Q O M F I W V R Q B B T B D G H P E D P Z M B N Q S X M T M L G F B J
X H A C D P D S T P R O T G H G L E T P J T I F U V D A E X C I T A T I O N S B
D I X D T J W E F M P A K R D P O X L Q Q Z H D E N O C L R O Z F D Y P Q L Q O
T I I G W S W K J L P I Y J A E K A A N R P J J R A Y J Q N N Q G V O X A I G Q
Y Q R I E Y N W A P J I H X Z L O U O F X T S R C Y G F G D R D F J A I A T K C
N N S A O I W S O Q O B L X F U R N W S H G U S I J D U Y G N R H O R V M H P Z
R V S N C I M D K A M I E R V N Z N W T Q S V L Y W J C N Z C C D E I Q Z L W T
Q Q X C X O O V K A N O R Q L S Q U B T C B N U Y V L P H Y C S T S M D Y E V D
B R B T N U K M V W I K D S P K A Y P J H M A K U Q F J O N X A C X A D T G J F
I K R I H M D E X Q Y A W K Z G L Y K X V A X O O X K A P U M N O I M R E F C G
K J C S N H Q C A F Z W J M O M T X T N Y K C F Y K I D O V T H I F S H W D O A
E S X P H K F N W X Q Z R E S H N P S Q R Z O J V N Y O R B P W Z N E P U O Y Y
D P Y T K Z N E W K U W M S Q G V T W B I P L G Z A J D W G I L I U C G E U P M
H H X G E E V B G W H I W U M K B N S K A V G T M J I P P Z T V T E I Y F T X L
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Symmetry Point Sudoku

Complete the Sudoku Puzzle using these electronic structure symmetry points!

G, K, M, L, A, H, X, U, W

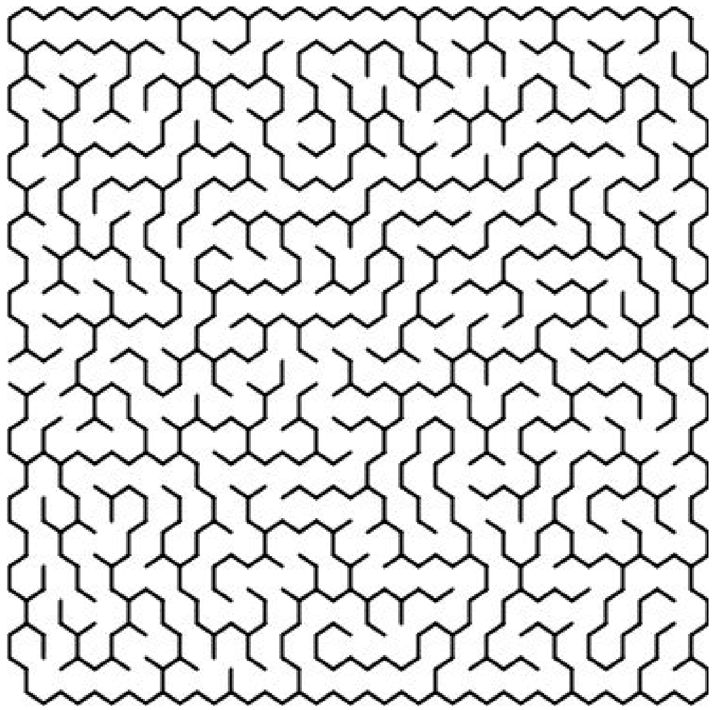
		W				U	M	
G		L		A			W	
							K	L
	K					H		
				M	X			
L			W	G				
			G	X				
	U		H			W		
					L			K

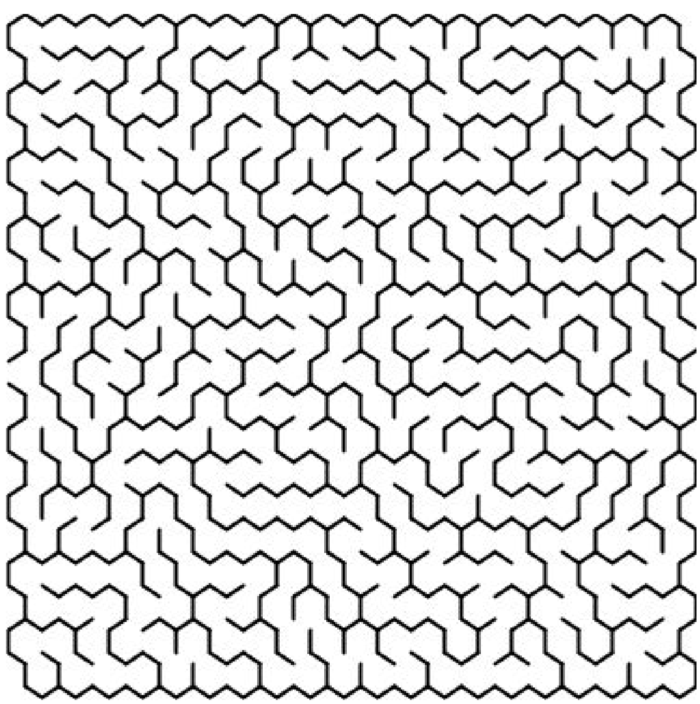
	W		K	M				
			U	G				
A	U					G		
	K				W			
	G			H	U	A		
	L		A	K	X	M	W	G
		U		X	K	W	M	
H	X							U
			H			X		

(For solutions, talk to Jason Haraldsen)

Honeycomb Lattice Maze

Navigate the vacancies in the honeycomb lattices!





Note Pages