# HKUST Institute for Advanced Study

# Symposium on Frontiers in Condensed Matter Physics –

## Topological Materials and Related Topics

**17 – 18 December 2012**

The Hong Kong University of Science and Technology

## Contents

# Program Schedule

Chen Kuan Cheng Forum (LT-H), HKUST *[except where indicated]*

| **17 December 2012 (Monday)** | | |
|---|---|---|
| *Time* | *Event* | *Presenter* |
| 8:30 – 9:00 | Registration | |
| 9:00 – 9:10 | Welcome Remarks | Henry Tye *[HKUST Institute for Advanced Study]* |
| 9:10 – 9:45 | Talk on "Quantum Spin Liquids and their Experimental Signatures" | Patrick A. Lee *[Massachusetts Institute of Technology and HKUST Institute for Advanced Study]* |
| 9:45 – 10:20 | Talk on "Emergent Exotic Statistics for Quasiparticle Excitations in Discrete Models for 2d Topological Phases" | Yong-Shi Wu *[University of Utah]* |
| 10:20 – 10:55 | Talk on "Momentum Polarization: An Entanglement Measure of Topological Spin" | Xiao-Liang Qi *[Stanford University]* |
| 10:55 – 11:15 | Refreshments/Group Photo | |
| 11:15 – 11:50 | Talk on "The Space Group Classification of Topological Band Insulators" | Jan Zaanen *[Leiden University]* |
| 11:50 – 12:25 | Talk on "Topological Phases with Spin-orbit Coupling on Pyrochlore Lattice" | Yong-Baek Kim *[University of Toronto]* |
| 12:25 – 14:00 | Lunch Break | |
| 14:00 – 17:00 | Poster Session<br>outside Padma and Hari Harilela Lecture Theater (LT-C) | |

| 18 December 2012 (Tuesday) | | |
|---|---|---|
| *Time* | *Event* | *Presenter* |
| 9:00 – 9:35 | Talk on "Optical Signature of Inversion Symmetry and Spin-valley Coupling in Atomically Thin Dichalcogenides" | Xiao-Dong Cui *[The University of Hong Kong]* |
| 9:35 – 10:10 | Talk on "Field Theory and Wave Function of Symmetry Protected Topological Phases " | Cenke Xu *[University of California at Santa Barbara]* |
| 10:10 – 10:45 | Talk on "Anomalous Josephson Effect in s-Wave Superconductor Junctions" | Kwok Sum Chan *[City University of Hong Kong]* |
| 10:45 – 11:15 | Refreshments | |
| 11:15 – 11:50 | Talk on "Network Model for Anderson Localization in Two-dimensional Electron Gas with Strong Spin-orbit Coupling" | Akira Furusaki *[RIKEN]]* |
| 11:50 – 12:25 | Talk on "Theory of a Quantum Spin Nematic Phase in a Quantum Magnet" | Ryuichi Shindou *[RIKEN]* |
| 12:25 – 14:00 | Lunch Break | |
| 14:00 – 14:35 | Talk on "Statistics of Holes and Nature of Superfluid Phases in Quantum Dimer Models" | Masaki Oshikawa *[University of Tokyo]* |
| 14:35 – 15:10 | Talk on "Odd-frequency Pairing and Majorana Fermion in Nanowire Proximity Systems" | Yukio Tanaka *[Nagoya University]* |
| 15:10 – 15:45 | Talk on "Quantum Spin Liquids in the Vicinity of Mott Transition" | Yi Zhou *[Zhejiang University]* |
| 15:45 – 15:55 | Closing Remarks | Patrick A. Lee *[Massachusetts Institute of Technology and HKUST Institute for Advanced Study]* |
| 18:00 – 20:00 | Dinner at UC Bistro, University Center (by invitation only) | |

# Abstracts

**Anomalous Josephson Effect in s-Wave Superconductor Junctions**

**Kwok Sum Chan[1,2]***

[1]**Department of Physics and Materials Science, City University of Hong Kong, Hong Kong**

[2]**Center for Functional Photonics, City University of Hong Kong, Hong Kong**

***Email of Presenting Author: apkschan@cityu.edu.hk**

In usual Josephson junctions, the supercurrent is zero, when the two superconducting leads have zero phase difference. However, non-zero supercurrent exists in some junctions even when the superconducting leads have zero phase difference, and this effect is referred to as the anomalous Josephson effect. There were three theoretical studies reported in Physical Review Letters [1-3] on this effect in s-wave Josephson junctions, which do not agree with each other on the necessary conditions for the existence of the anomalous effect. In this talk I will present our study of the existence conditions from the symmetry point of view [4]. I will also present our study [5] of the anomalous supercurrent in a ferromagnetic trilayer Josephson junction, which is found to be the result of the triplet pairing created by spin rotation in the ferromagnetic layers and scattering by the interfaces.

References:

[1] A. Buzdin, Phys. Rev. Lett. 101, 107005 (2008).

[2] A. A. Reynoso, Gonzalo Usaj, C. A. Balseiro, D. Feinberg, and M. Avignon, Phys. Rev. Lett. 101, 107001 (2008).

[3] A. Zazunov, R. Egger, T. Jonckheere, and T. Martin, Phys. Rev. Lett. 103, 147004 (2009).

[4] J. F. Liu and K. S. Chan, Phys. Rev. B, 82, 125303 (2010).

[5] J. F. Liu and K. S. Chan, Phys. Rev. B, 82, 184533 (2010).

## Optical Signature of Inversion Symmetry and Spin-valley Coupling in Atomically Thin Dichalcogenides

**Xiao-Dong Cui***

**Department of Physics, The University of Hong Kong, Hong Kong**

***Email of Presenting Author: xdcui@hku.hk**

Motivated by the triumph and limitation of graphene for electronic applications, atomically thin layers of group VI transition metal dichalcogenides are attracting extensive interest as a class of graphene-like semiconductors with a desired band-gap in the visible frequency range. The monolayers feature a valence band spin splitting with opposite sign in the two valleys located at corners of the 1st Brillouin zone. This spin-valley coupling, particularly pronounced in tungsten dichalcogenides, can benefit potential spintronics and valleytronics with the important consequences of spin-valley interplay and the suppression of spin and valley relaxations. Here we report the first optical studies of WS2 and WSe2 monolayers and multilayers. The efficiency of second harmonic generation (SHG) shows a dramatic even-odd oscillation consistent with the presence (absence) of inversion symmetry in even (odd) layer. Photoluminescence (PL) measurements show the crossover from an indirect band gap semiconductor at mutilayers to a direct-gap one at monolayers. The PL spectra and first-principle calculations consistently reveal a spin-valley coupling of 0.4 eV which suppresses interlayer hopping and manifests as a thickness independent splitting pattern at valence band edge near K points. This giant spin-valley coupling, together with the valley dependent physical properties, may lead to rich possibilities for manipulating spin and valley degrees of freedom in these atomically thin 2D materials.

**Network Model for Anderson Localization in Two-dimensional Electron Gas with Strong Spin-orbit Coupling**

**Akira Furusaki**

**Condensed Matter Theory Lab., RIKEN Advanced Science Institute, Japan**

***Email of Presenting Author: furusaki@riken.jp**

I will review results of our numerical studies on the Anderson localization problem in two-dimensional electron gas with strong spin-orbit coupling [1]. The electronic transport in such electron gas can be effectively simulated using a network model for the symplectic class, which is two sheets of the Chalker-Coddington network model (for up and down spin electrons) coupled by spin-flip scattering matrices. In this formulation a two-dimensional topological insulator (quantum spin Hall) phase and an ordinary insulating phase are distinguished merely by the boundary condition imposed on the network model. It is therefore natural to expect (as numerically confirmed) that critical properties are the same for a metal-to-(normal insulator) transition and a metal-to-(topological insulator) transition. However, a clear distinction between the two types of metal-to-insulator transitions can be seen in boundary multifractal spectra of critical wave functions. I will discuss boundary multifractality and its connection to conformal invariance.

References:

[1] H. Obuse, A. R. Subramaniam, A. Furusaki, I. A. Gruzberg and A. W. W. Ludwig, Phys. Rev. B 82, 035309 (2010); H. Obuse, A. Furusaki, S. Ryu and C. Mudry, Phys. Rev. B 78, 115301 (2008); ibid., Phys. Rev. B 76, 075301 (2007).

**Topological Phases with Spin-orbit Coupling on Pyrochlore Lattice**

**Yong-Baek Kim***

**Department of Physics, University of Toronto, Canada**

***Email of Presenting Author: ybkim@physics.utoronto.ca**

Recently there have been significant theoretical and experimental efforts to understand and identify topological phases in interacting electron systems with strong spin-orbit coupling. We consider interacting electrons on the pyrochlore lattice and investigate possible topological and related phases in the presence of strong spin-orbit coupling.

Novel topological phases in the strong and intermediate-strength interaction regimes are investigated. Applications to 5d transition metal oxides and related systems are discussed.

**Quantum Spin Liquids and their Experimental Signatures**

**Patrick A. Lee***

**Massachusetts Institute of Technology, USA and HKUST Institute for Advanced Study, Hong Kong**

***Email of Presenting Author: palee@mit.edu**

I shall review recent progress in identifying spin liquid candidates, emphasizing the open questions that remain. I also discuss a number of proposed new experiments such as sound attenuation, ARPES, neutron scattering and optical absorption which may help resolve these questions.

**Statistics of Holes and Nature of Superfluid Phases in Quantum Dimer Models**

**C. A. Lamas[1], A. Ralko[2], M. Oshikawa[3]*, D. Poilblanc[1], P. Pujol[1]**

**[1]Laboratoire de Physique Théorique, IRSAMC, CNRS and Université de Toulouse, France**

**[2]Institut Néel, CNRS and Université Joseph Fourier, France**

**[3]Institute for Solid State Physics, University of Tokyo, Japan**

***Email of Presenting Author: oshikawa@issp.u-tokyo.ac.jp**

Quantum Dimer Models (QDM) arise as low energy effective models for frustrated magnets, and host exotic spin liquid phases with deconfined spinons. We consider doping of holes into the spin liquid phases of the QDM. A fundamental issue is the possible existence of a superconducting phase in such systems and its properties. For this purpose, the question of the statistics of the mobile holes (or "holons") shall be addressed first. We prove general "statistical transmutation" symmetry of such doped QDM by using composite operators of dimers and holes. This exact transformation enables one to define duality equivalence classes (or families) of doped QDM, and provides the analytic framework to analyze dynamical statistical transmutations. We discuss various possible superconducting phases of the system. In particular, the possibility of an exotic superconducting phase originating from the condensation of (bosonic) charge-*e* holons is examined. A numerical evidence of such a superconducting phase, based on a novel gauge-invariant holon Green's function, is presented in the case of the QDM on a triangular lattice.

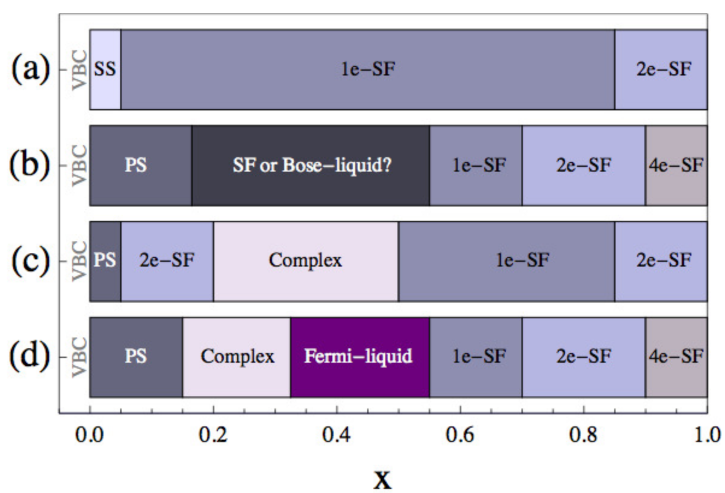


Figure 1: Schematic phase diagram of various versions of doped QDM on the triangular lattice, as a function of doping concentration *x*. The exotic superfluid phase due to condensation of charge-*e* holon (1e-SF) is suggested for a range of doping concentration *x*.

Reference:

C. A. Lamas, A. Ralko, M. Oshikawa, D. Poilblanc, and P. Pujol, arXiv:1210.1270

**Momentum Polarization: An Entanglement Measure of Topological Spin**

**Xiao-Liang Qi***

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Topologically ordered states are states of matter which are distinct from trivial states by topological properties such as ground state degeneracy and quasi-particles carrying fractional quantum numbers and fractional statistics. The topological spin is an important property of a topological quasi-particle, which is the Berry phase obtained in the adiabatic self-rotation of the quasi-particle by 2. In this paper we propose a new approach to compute the topological spin in candidate systems of two-dimensional topologically ordered states. We identify the topological spin with a new quantity, the momentum polarization defined on the cylinder geometry. We show that the momentum polarization is determined by the quantum entanglement between the two halves of the cylinder, and can be computed from the reduced density matrix. As an example we present numerical results for the honeycomb lattice Kitaev model, which correctly reproduces the expected spin 1/16 of the Ising non-Abelian anyon. Our result provides a new efficient approach to characterize and identify topological states of matter from finite size numerics.

**Theory of a Quantum Spin Nematic Phase in a Quantum Magnet**

**Ryuichi Shindou***

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Quantum spin nematic (QSN) phase is a novel quantum phase of matter in magnets, which can be regarded as a quantum-spin analogue of nematic liquid crystal phase. The phase possesses neither any orderings of spin moment, nor crystalline solid-like structure in spin degrees of freedom. But, unlike spin-rotational symmetric quantum spin liquids (QSL), it exhibits an ordering of rank-2 traceless tensor spin operators, which are composed of two distinct spin operators defined on spatially different sites. Ground-state spin wavefunctions of QSN are essentially given by quantum-mechanical superpositions of a number of spatial partitionings of spin-triplet valence bonds and/or spin-singlet valence bonds, sharing similar features as those of QSL. Based on this observation, we describe these ground-state wavefunctions in terms of spin-triplet variants of Anderson's resonating valence bond (RVB) state, so as to explore their possible realization in a certain realistic quantum frustrated model. We argue that dynamical spin structure factor in a QSN phase exhibit characteristic features at low-temperature regime, such as 'gauge-field' like collective modes with a finite spectral weight and continuum spectrum associated with gapped spinon band.

Due to the Raman process associated with gapless director (spin) waves, the NMR relaxation rate in the same low-temperature (T) regime exhibits $T^{2d-1}$ behavior where d is the effective spatial dimension.

**Odd-frequency Pairing and Majorana Fermion in Nanowire Proximity Systems**

**Yukio Tanaka[1]*, Yasuhiro Asano[2]**

[1]**Department of Applied Physics, Nagoya University, Japan**

[2]**Department of Applied Physics, Hokkaido University, Japan**

***Email of Presenting Author: ytanaka@nuap.nagoya-u.ac.jp**

Superconductivity is a phenomenon where the macroscopic quantum coherence appears due to the pairing of electrons. The symmetry properties of the pairing, i.e., the parity and spin-singlet/spin-triplet, determine the physical properties of the superconducting state. Recently it has been recognized that there is the important third symmetry of the pair amplitude, i.e., even or odd parity with respect to the frequency [1]. The conventional uniform superconducting states correspond to the even-frequency pairing, but the recent finding is that the odd-frequency pair amplitude arises in the spatially non-uniform situation quite ubiquitously [2]. Especially, this is the case in the Andreev bound state (ABS) appearing at the surface/interface of the sample. It has been revealed that there are many exotic properties relevant to odd-frequency pairing like anomalous proximity effect in spin-triplet superconductor junctions [3,4]. Here, we discuss a strong relationship between Majorana fermions and odd-frequency Cooper pairs which appear at a disordered normal (N) nano wire attached to a topologically nontrivial superconducting (S) one. The transport properties in superconducting nano wire junctions show universal behaviors irrespective of the degree of disorder: the quantized zero-bias differential conductance in NS junction and the fractional current-phase relationship of the Josephson effect in SNS junction. These behaviors are exactly the same as those in the anomalous proximity effect of odd-parity spin-triplet superconductors. The odd-frequency pairs exist wherever the Majorana fermions stay [5].

References:

[1] Y. Tanaka, M. Sato and N. Nagaosa, J. Phys. Soc. Jpn. 81, 011013 (2012).

[2] Y. Tanaka, A. A. Golubov, S. Kashiwaya and M. Ueda, Phys. Rev. Lett. 99, 037005 (2007).

[3] Y. Tanaka and A. A. Golubov, Phys. Rev. Lett. 98, 037003 (2007).

[4] Y. Tanaka and S. Kashiwaya, Phys. Rev. B 70, 012507 (2004).

[5] Y. Asano and Y. Tanaka, arXiv:1204.4226.

**Emergent Exotic Statistics for Quasiparticle Excitations in Discrete Models for 2d Topological Phases**

**Yuting Hu[1], S. D. Spencer[1,2], Yong-Shi Wu[1,3]***

[1]**Department of Physics and Astronomy, University of Utah, USA**

[2]**Department of Mathematics, University of Utah, USA**

[3]**State Key Laboratory of Surface Physics, Department of Physics and Center of Field Theory and Particle Physics, Fudan University, China**

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In this talk we will demonstrate how exotic quantum statistics, including both braiding statistics and exclusion statistics, emerge for quasiparticle excitations in exactly solvable discrete models for 2d topological phases, such as fluxons in the Levin-Wen model. We have succeeded in constructing explicit operators to identify the excitation configurations and to implement hopping of excitations, and used numerical methods to identify the statistical parameters.

**Field Theory and Wave Function of Symmetry Protected Topological Phases**

**Cenke Xu***

**Department of Physics, University of California at Santa Barbara, USA**

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We will start with a general discussion of the field theory of symmetry protected topological phases, including the ground state wave function, entanglement spectrum that can be derived from the field theory. We will also discuss the general applicability of the field theory. Then we will discuss two classes of symmetry protected topological phases. The first class is the SPT phases in arbitrary odd spatial dimensions with PSU(N) symmetry, the second class is the SPT phases in even spatial dimensions with PSU(N) x TR symmetry. In both cases, we will discuss their field theory descriptions, and their lattice construction. The topological part of the field theory can be precisely derived/reproduced from the lattice construction. We will also argue that the boundary of the SPT phases cannot be realized as a lower dimensional system with the same symmetry as the bulk SPT.

**The Space Group Classification of Topological Band Insulators**

**Jan Zaanen***

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The existing classification for topological band insulators (TBI's) departs from time reversal symmetry but the role of the crystal lattice symmetries remained elusive. We [1,2] have discovered a classification for TBI's, which we believe is complete, based on both time reversal as well as the symmetries of the ionic lattice. In this classification, the TBI's protected by time reversal fall in two subclasses: the "Gamma type" and the "translationally active" TBI's where the latter are destroyed by crystalline topological disorder (dislocations [2]). In addition, we identify "valley" or "crystalline" TBI's which are exclusively protected by lattice symmetries, where the "weak" 3D TBI's form a subclass only protected by 2D point group symmetries. We propose a general system of indices to characterize all TBI's based on space-group classification. We show that there are 17 thermodynamically different TBI's in 2D and more than 70 in 3D.

References:

[1] R. J. Slager, A. Mesaros, V. Juricic and J. Zaanen, Nature Phys. (in press, arXiv:1209.2610).

[2] A. Mesaros, R. J. Slager, J. Zaanen and V. Juricic, Nucl. Phys. B (in press, arXiv:1208.5708).

**Quantum Spin Liquids in the Vicinity of Mott Transition**

**Yi Zhou[1]*, Tai-Kai Ng[2]**

**[1]Department of Physics, Zhejiang University, China**

**[2]Department of Physics, The Hong Kong University of Science and Technology, Hong Kong**

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Starting from Fermi liquid theory of electrons from the metallic side, we propose an alternative picture to the Brinkman-Rice picture of Mott metal-insulator transition where the (insulating) spin-liquid states are viewed as Fermi liquid states with singular Landau parameter $F_{1s}$. The charge and spin transport properties and electromagnetism of spin liquid states are studied under such a phenomenology. The appearance and consequences of Pomeranchuk instability to spin-liquid states are discussed.

## Posters

### Spin Density Wave Fluctuations and p-wave Pairing in $Sr_2RuO_4$

**J. Huo[1]*, T. M. Rice[1,2,3], Fuchun Zhang[1]**

**[1]Department of Physics, The University of Hong Kong, Hong Kong**

**[2]Condensed Matter Physics and Material Science Department, Brookhaven National Laboratory, USA**

**[3]Institut für Theoretische Physik, ETH Zürich, Switzerland**

***Email of Presenting Author: jiaweihuo@gmail.com**

$Sr_2RuO_4$ displays strong spin density wave (SDW) fluctuations at an incommensurate nesting wavevector spanning the Fermi surfaces of the ($\alpha$,$\beta$) bands [1]. SDW fluctuations at this wavevector Q=($2\pi/3$,$2\pi/3$) were recently reported at room temperature and at energies as high as 80 meV [2]. The SDW peaks at Q which combine nesting in both nearly 1D Fermi surfaces grow as the temperature is reduced and saturate at the crossover to 3D Fermi liquid behavior at $T_{3D}$, around 130 K. To date these have been discussed within a random phase approximation (RPA) scheme [3]. Because of the highly nesting character of the ($\alpha$,$\beta$) Fermi surface, it is necessary to choose a very weak interaction in RPA with a value typically an order of magnitude smaller than standard estimates. Here we show that treating the 1D character of the ($\alpha$,$\beta$) bands in a renormalization group (RG) scheme, can explain the absence of SDW order at $T>T_{3D}$ using a standard value for the interaction. Another consequence of the RG scheme is the suppression of the p-wave pairing susceptibility in the 1D bands, when the SDW fluctuations are enhanced.

References:

[1] M. Braden, Y. Sidis, P. Bourges, P. Pfeuty, J. Kulda, Z. Mao, and Y. Maeno, Phys. Rev. B 66, 064522 (2002).

[2] K. Iida, M. Kofu, N. Katayama, J. Lee, R. Kajimoto, Y. Inamura, M. Nakamura, M. Arai, Y. Yoshida, M. Fujita, K. Yamada, and S. H. Lee, Phys. Rev. B 84, 060402 (2011).

[3] I. I. Mazin and D. J. Singh, Phys. Rev. Lett. 82, 4324 (1999).

**Robust Topological Insulator Surface Conduction under Strong Surface Disorder**

**Liang Du[1], Quansheng Wu[1], Vincent Sacksteder IV[1]***

**[1]Institute of Physics, Chinese Academy of Sciences, China**

***Email of Presenting Author: vincent@sacksteder.com**

Topological insulators are characterized by specially protected conduction on their outer boundaries, i.e. on their surfaces. We show that the protected surface conduction exhibited by 2-D topological insulators is independent of non-magnetic surface disorder. In particular, the surface band remains conducting even when surface state inhomogeneities destroy the characteristic linear Dirac relation between energy and momentum. The main effects of disorder are to pull the surface states into the disordered layers, decrease their Fermi velocity, and increase the density of states. These effects are controlled by a resonance between the disorder potential and the bulk bands. The resonance's energy is set by the bulk band width; protection of the Dirac cone is controlled by the bulk band width, not the bulk band gap.

# Pinning of Fermionic Occupation Numbers

**Christian Schilling[1]*, David Gross[2], Matthias Christandl[3]**

**[1]Institute for Theoretical Physics, ETH Zürich, Switzerland**

**[2] Institute for Physics, University of Freiburg, Germany**

**[3]Institute for Theoretical Physics, ETH Zürich, Switzerland**

***Email of Presenting Author: schilling@itp.phys.ethz.ch**

We would like to present our latest findings on the “Pinning of Fermionic Occupation Numbers” [1]: The Pauli Exclusion Principle is a constraint on the natural occupation numbers of fermionic states. It has been suspected since at least the 1970’s, and only proved very recently, that there is a multitude of further constraints on these numbers, strengthening the Pauli principle. Here, we provide the first analytic analysis of the physical relevance of these constraints. We compute the natural occupation numbers for the ground states of a family of interacting fermions in a harmonic potential. Intriguingly, we find that the occupation numbers are almost, but not exactly, pinned to the boundary of the allowed region (quasipinned). The result suggests that the physics behind the phenomenon is richer than previously appreciated. In particular, it shows that for some models, the generalized Pauli constraints play a role for the ground state, even though they do not limit the ground-state energy. Our findings suggest a generalization of the Hartree-Fock approximation.

Reference:

[1] C. Schilling, D. Gross and M. Christandl, arXiv:1210.5531 [quant-ph] (accepted by PRL).

**Majorana Bound States and Disclinations in Topological Crystalline Superconductors**

**Jeffrey C.Y. Teo*, Taylor L. Hughes**

**Department of Physics, University of Illinois at Urbana-Champaign, USA**

***Email of Presenting Author: cteo@illinois.edu**

We prove a topological criterion for the existence of zero-energy Majorana bound-state on a disclination, a rotation symmetry breaking point defect, in 4-fold symmetric topological crystalline superconductors (TCS). We first establish a complete topological classification of TCS using the Chern invariant and three integral rotation invariants. By analytically and numerically studying disclinations, we algebraically deduce a $Z_2$-index that identifies the parity of the number of Majorana zero-modes at a disclination. Surprisingly, we also find weakly-protected Majorana fermions bound at the corners of superconductors with trivial Chern and weak invariants.

**Fractional Quantum Hall States with Anisotropic Interactions**

**Hao Wang[1,*], Rajesh Narayanan[1,2,3], Xin Wan[4], Fuchun Zhang[1,4]**

**[1]Department of Physics, The University of Hong Kong, Hong Kong**

**[2]Department of Physics, Indian Institute of Technology Madras, India**

**[3]Department of Physics, The Hong Kong University of Science and Technology, Hong Kong**

**[4]Zhejiang Institute of Modern Physics, Zhejiang University, China**

***Email of Presenting Author: wangh75@hku.hk**

We would like to present our recent study of the anisotropic effect of the Coulomb interaction on a 1/3-filling fractional quantum Hall system using exact diagonalization method on small systems in torus geometry. For weak anisotropy the system remains to be an incompressible quantum liquid, although anisotropy manifests itself in density correlation functions and excitation spectra. When the strength of anisotropy increases, we find the system develops a Hall-smectic-like phase with one-dimensional charge density wave order and is unstable towards the one-dimensional Wigner crystal in the strong anisotropy limit. In all three phases of the Laughlin liquid, Hall-smectic-like, and crystal phases the ground state of the anisotropic Coulomb system can be well described by a family of model wavefunctions generated by an anisotropic projection Hamiltonian. Our work is relevant to the geometrical description of FQHE system proposed by Haldane [Phys. Rev. Lett. 107, 116801 (2011)].

**Multilayer Graphene Systems**

**Jie Yuan[1,*], Jin-Hua Gao[2,1,2] , Dong-Hui Xu[3], Yi Zhou[3], Zi-Jian Yao[1] , Hao Wang[1], Fuchun Zhang[1,3]**

**[1]Department of Physics and Centre of Theoretical and Computational Physics, The University of Hong Kong, Hong Kong**

**[2]Department of Physics, Huazhong University of Science and Technology, China**

**[3]Department of Physics, Zhejiang University, China**

***Email of Presenting Author: phyyuan@gmail.com**

We would like to present our latest findings on multilayer graphene systems. Based on recent transport experimental data, we use Hubbard model to detect the systems. In bilayer grapheme (BLG), a spontaneous gap about 2meV is fitted when U=6.44eV. The symmetry-breaking state is layer anti-ferromagnetic state. In the presence of external electric field, a gap-closing is observed when the applied perpendicular electric field is about E=15.0 mV $nm^{-1}$. A first-order phase transition occurs with vanishing spin polarizations. At that time, the system becomes a half-metal.

In the trilayer grapheme (TLG), the system will have a different conducting behavior depending on the stacking order. ABC stacked TLG has an insulating gap about 6meV as detected in experiment, but ABA TLG shows no insulating gap. We attribute it as the effect of the Hubbard interaction. The two systems have a rather different behavior responding to the interactions. When U=6.2eV, ABC TLG has the expected insulating gap, while in ABA system, it is much smaller, about 1T. The two-stacking ordered graphene possesses different magnetic structures. We also generalize the results to the many-layer graphene systems.

Reference:

Dong-Hui Xu, Jie Yuan, Zi-Jian Yao, Yi Zhou, Jin-Hua Gao, Fuchun Zhang, Phys. Rev. B 86, 201404(R)(2012).

# General Information and Maps

*Catering Facilities on Campus*

| Restaurants | Types of Food | Location |
|---|---|---|
| China Garden Restaurant | Chinese dim sum, and Peking & Cantonese dishes | G/F (near Lifts 13-15) |
| Coffee Shop and Coffee Kiosk | Hot meals, sandwiches, baked potatoes, snacks, pastries, fruits, desserts and drinks | 1/F (near Lifts 25-26) |
| LG1 Canteens | Fast food, sandwiches, snacks and desserts | LG1 (via Lifts 10-12 / 13-15) |
| LG7 Canteens | Hong Kong and Asian style fast food | LG7 (via Lifts 10-12) |
| McDonald's | Burgers, fast food | LG5 (via Lifts 10-12) |
| UC Bistro | Western menu, lunch, dinner and snacks | Lo Ka Chung University Center |

*Wireless Internet Access*

Wireless network "**sMobileNet**" is available in the conference venue, catering outlets and most of the public areas on campus:

***User name = iasguest***

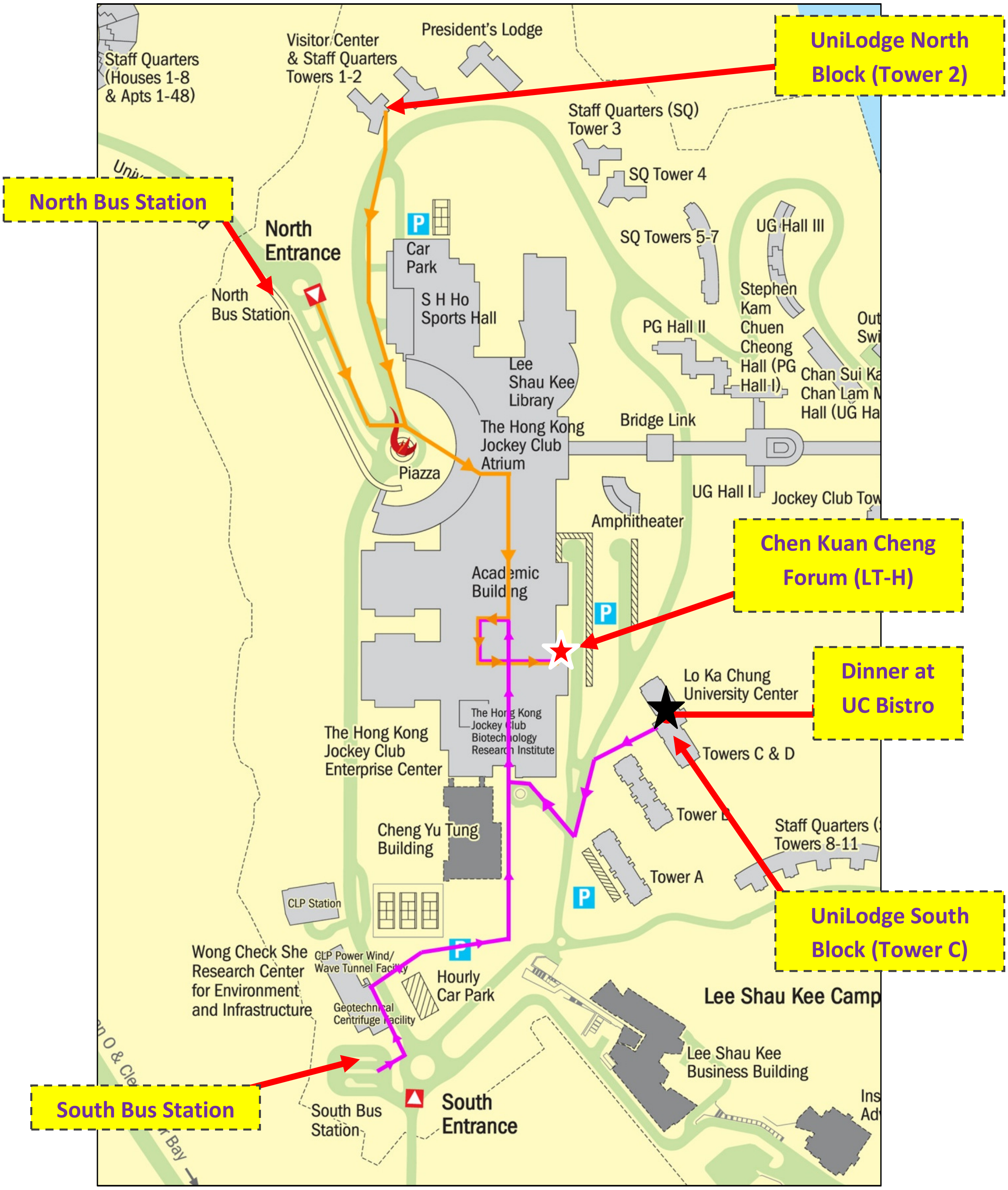
***Password =*** **Removed**

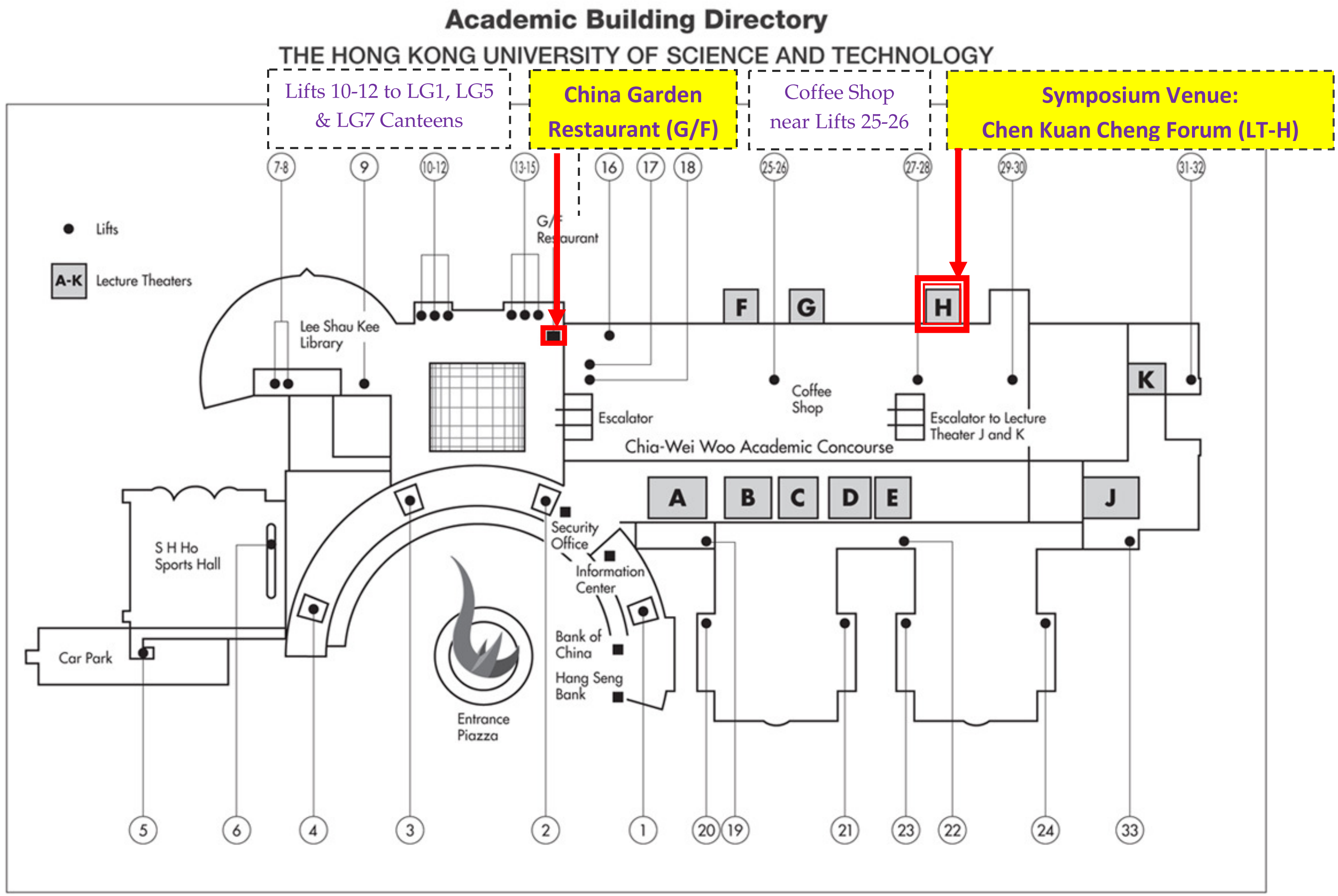
Free wireless Internet service "**GovWiFi**" is also available at some public premises and designated tourist spots in town.

*Useful Phone Numbers*

| | |
|---|---|
| APW Secretariat (HKUST IAS) | 2358-5912 / 2358-5062 |
| China Garden Restaurant | 2358-1133 |
| UC Bistro (Reservations) | 2335-1875 |
| Campus Security | 2358-6565 |
| Royal Pacific Hotel and Towers | 2736 1188 |
| Crowne Plaza Kowloon East | 3983 0388 |
| Holiday Inn Express Kowloon East | 3199 5588 |
| Emergency / Ambulance | 999 / 2358-8999 |
| Local Telephone Directory Inquiry | 1081 (English) / 1083 (Chinese) |

## Walking Routes from Bus Stations / UniLodges to Lecture Theater H




Academic Building Directory
THE HONG KONG UNIVERSITY OF SCIENCE AND TECHNOLOGY
Lifts 10-12 to LG1, LG5 & LG7 Canteens
China Garden Restaurant (G/F)
Coffee Shop near Lifts 25-26
Symposium Venue: Chen Kuan Cheng Forum (LT-H)
Lifts
A-K Lecture Theaters
G/F Restaurant
Lee Shau Kee Library
Escalator
Coffee Shop
Escalator to Lecture Theater J and K
Chia-Wei Woo Academic Concourse
S H Ho Sports Hall
Car Park
Security Office
Information Center
Bank of China
Hang Seng Bank
Entrance Piazza