# Index

# Program

The First Week

| | Workshop | | | | Seminar | |
|---|---|---|---|---|---|---|
| | Monday 27/8 | Tuesday 28/8 | Thursday 30/8 | Friday 31/8 | **Wednesday 29/8** | |
| **Chair** | Yi Zhou | Yuan Wan | Zhengxin Liu | Daoxin Yao | **Chair** | Qingming Zhang |
| 10:00-10:15 | F.C. Zhang | | | | 9:00-9:45 | Anders Sandvik |
| 10:15-11:00 | Philippe Mendels | Oleg Tchernyshyov | Yi Zhou | Joseph Betouras | 9:45-10:15 | Wanjun Jiang |
| 11:00-11:15 | Coffee Break | | | | 10:15-10:40 | Coffee Break |
| | | | | | **Chair** | Lei Shu |
| 11:15-12:00 | Zhengyu Weng | Jianxin Li | Qingming Zhang | Yayu Wang | 10:40-11:10 | Daoxin Yao |
| 12:00-16:00 | Lunch Break | | | | 11:10-11:40 | Yuan Li |
| 16:00-16:45 | Bruce Normand | Honghao Tu | R. Ganesh | Judit Romhanyi | 11:40-12:10 | Chenjie Wang |
| 16:45-17:30 | | | Poster Session① | | 12:10-14:00 | Lunch |
| | | | | | **Chair** | Honghao Tu |
| | | | | | 14:00-14:45 | Ciaran Hickey |
| | | | | | 14:45-15:15 | Zhiyuan Xie |
| | | | | | 15:15-15:40 | Coffee Break |
| | | | | | **Chair** | Chenjie Wang |
| | | | | | 15:40-16:10 | Sungkit Yip |
| | | | | | 16:10-16:40 | Zhengxin Liu |
| | | | | | 16:40-17:10 | Lei Shu |
| | | | | | 17:10-17:40 | Shiyan Li |

① In this session, poster submitters will give a brief presentation, 2 minute for each person, presentation order please see the poster list.

The Second Week

| | Workshop | | | | Seminar | |
|---|---|---|---|---|---|---|
| | Monday 3/9 | Tuesday 4/9 | Wednesday 5/9 | Thursday 6/9 | **Friday 7/9** | |
| **Chair** | Yuan Li | Gang Chen | Weiqiang Yu | Ling Wang | **Chair** | Jie Ma |
| | | | | | 9:00-9:45 | Bella Lake |
| 10:15-11:00 | Andreas Honecker | Yongbaek Kim | Hirokazu Tsunetsugu | Frank Verstraete | 9:45-10:15 | Haijun Liao |
| 11:00-11:15 | Coffee Break | | | | 10:15-10:40 | Coffee Break |
| | | | | | **Chair** | Yang Qi |
| 11:15-12:00 | Masashi Takigawa | Guangming Zhang | Jianlin Luo | Weiqiang Yu | 10:40-11:10 | Lixin He |
| 12:00-16:00 | Lunch Break | | | | 11:10-11:40 | Shiliang Li |
| 16:00-16:45 | Radu Coldea | Keisuke Totsuka | Philippe Corboz | Itamar Kimchi | 11:40-12:10 | Wenan Guo |
| | | | | | 12:10-14:00 | Lunch |
| | | | | | **Chair** | Shiliang Li |
| | | | | | 14:00-14:45 | Gregoire Misguich |
| | | | | | 14:45-15:15 | Jie Ma |
| | | | | | 15:15-15:40 | Coffee Break |
| | | | | | **Chair** | Wenan Guo |
| | | | | | 15:40-16:25 | Chisa Hotta |
| | | | | | 16:25-16:55 | Zi Cai |
| | | | | | 16:55-17:25 | Yang Qi |

The Third Week

| | Workshop | | | | Seminar | |
|---|---|---|---|---|---|---|
| | Tuesday 11/9 | Wednesday 12/9 | Thursday 13/9 | Friday 14/9 | **Monday 10/9** | |
| **Chair** | Rong Yu | Tao Li | Ryuichi Shindou | | **Chair** | Fa Wang |
| | | | | | 9:00-9:45 | Ashvin Vishwanath |
| 10:15-11:00 | Arnab Sen | Yasir Iqbal | Federico Becca | | 9:45-10:15 | Ziyang Meng |
| 11:00-11:15 | Coffee Break | | | | 10:15-10:40 | Coffee Break |
| | | | | | **Chair** | Zi Cai |
| 11:15-12:00 | Didier Poilblanc | Gang Su | Gang Chen | | 10:40-11:10 | Ling Wang |
| 12:00-16:00 | Lunch Break | | | | 11:10-11:40 | Yuan Wan |
| 16:00-16:45 | Andreas Laeuchli | Frank Pollmann | Hosho Katsura | | 11:40-12:10 | Jinguang Cheng |
| | | | | | 12:10-14:00 | Lunch |
| | | | | | **Chair** | Jinguang Cheng |
| | | | | | 14:00-14:30 | Shoushu Gong |
| | | | | | 14:30-15:00 | Xuefeng Sun |
| | | | | | 15:00-15:25 | Coffee Break |
| | | | | | **Chair** | Ziyang Meng |
| | | | | | 15:25-16:10 | Stefan Wessel |
| | | | | | 16:10-16:40 | Tao Li |
| | | | | | 16:40-17:10 | Xuefeng Zhang |

# Venue

M-Building, Institute of Physics, Chinese Academy of Sciences (IoP,CAS)

M-Building Rm.236: Aug 27 & Aug 29--Sep14

M-Building Rm.253: Aug 28

**Address:** No.8, 3rd South Street, Zhongguancun, Haidian Distric, Beijing, 100190, China

地址：中国科学院物理研究所 M 楼，北京海淀区中关村南三街 8 号

## How to get to the conference venue:

**By Taxi**

You could show the following message to the driver， taxi fee is about 100 RMB:

| |
|---|
| Please take me to M Building, IOP, CAS<br>Please give me an invoice, thank you!<br><br>请送我去中国科学院物理研究所 M 楼<br>（地址：北京海淀中关村南三街 8 号）<br>请给我一张发票，谢谢 |

Note: Please go to the taxi area at the airport to take taxis. Do not trust anybody who approach and offer a ride, even when they claim themselves as taxi drivers/companies.

**By Metro**

Take the Airport express Line at the airport to Sanyuanqiao Station → Transfer to Line 10 to get off at Zhichunli Station， Leave the station at Exit D and walk to M Building (about 1.2km)

**By Airport Shuttle Bus:**

Take the Zhong-Guan-Cun line（中关村线） at the airport, get off at Bao-Fu-Si Bridge North Station （保福寺桥北站）(the last second stop) , walk to IOP (about 800m) .

The earliest shuttle bus is 6:50 and the latest is 24:00, the departure interval is usually half an hour.

# Hotel

## （一） Liaoning International Hotel

Location: No.2 A North 4th Ring Road West, Haidian District, Beijing

地址：北京市海淀区北四环西路甲 2 号

Tel: (+86) 010-62589999 Web：: http://liaoningdasha.com/en/index.htm

**How to get to this hotel：**

**By Taxi**

You could show the following message to the driver， taxi fee is about 100 RMB:

| |
|---|
| 请送我去辽宁大厦（地址：北京市海淀区北四环西路甲2号），谢谢！<br><br>请给我一张发票，谢谢！<br><br>Please take me to Liao-Ning International Hotel, Thank you!<br><br>Please also give me an invoice, thanks. |

Note: Please go to the taxi area at the airport to take taxis. Do not trust anybody who approach and offer a ride, even when they claim themselves as taxi drivers/companies.

**By Airport Shuttle Bus**

Take the Zhong-Guan-Cun line（中关村线） at the airport, get off at Bao-Fu-Si Bridge North Station（保福寺桥北站）(the last second stop) , walk to the hotel (about 500m) .

Metro is not very convenient to get to this hotel, it’s not suggested.

**（ 二 ） Park Plaza Beijing Science Park**

Location: 25 Zhi Chun Road, Haidian District, Beijing

地址：北京市海淀区知春路 25 号

Tel: (+86) 010-82356683　　Web: www.parkplaza.com/beijingcn_sciencepark

**How to get to the hotel：**

**By Taxi**

You could show the following message to the driver，taxi fee is about 100 RMB：

| |
|---|
| Please take me to Park Plaza Hotel, Thank you!<br>Please also give me an invoice, thanks.<br><br>请送我去丽亭华苑酒店，谢谢！<br>（地址：北京市海淀区知春路25号）<br><br>请给我一张发票，谢谢! |

Note: Please go to the taxi area at the airport to take taxis. Do not trust anybody who approach and offer a ride, even when they claim themselves as taxi drivers/companies.

**By Metro**

Take the Airport express Line at the airport to Sanyuanqiao Station → Transfer to Line 10 to get off at Zhichunlu Station，Leave the station at Exit F and walk to the hotel (about 400m)

# Registration

**All participants may register at the conference venue. Please sign your attendance.**

**Time：**

| | |
|---|---|
| **Aug 27** | **9:20-10:00** |
| **Aug 28—Sep 14** | **Half an hour before the first talk in the morning** |

**Location:**

| | |
|---|---|
| **Aug 27& Aug 29—Sep 14** | **M-Building, Rm. 236** |
| **Aug 28** | **M-Building, Rm. 253** |

**For overseas speakers, please:**

- **Provide the original boarding pass**
- **Sign the contract for bank remit**

# Abstracts

1

## Quantum kagome spin liquids: a local view

Philippe Mendels

*P. Mendels[1] F. Bert[1] J.C. Orain[1,2] , M. Velazquez[3] and P. Khuntia[1,4]*

*1 Laboratoire de physique des solides, Univ. Paris-Sud Orsay, Univ. Paris-Saclay*

*2 now at Paul Scherrer Institut,Villigen, Switzerland*

*3 ICMCB, Bordeaux*

*4 now at Indian Institute of Technology Madras, Chennai, India*

In my talk, I will present results on two kagome quantum spin liquids. 1- Herbertsmithite $ZnCu_3(OH)_6Cl_2$ has been known since 2005 as one of the best representative of spin liquid physics for the Heisenberg model on a quantum kagome antiferromagnetic lattice (KHAF). While some quasi-free Cu on Zn sites mask the signature of the kagome physics at low-T in most experimental techniques, typically T < J/10, one can take advantage of the strong coupling of O to the kagome Cu's to track this physics through 17O NMR [1]. Recently, working on high quality single crystals considerably improved the accuracy of NMR measurements and its ability to address fundamental issues such as the existence of a gap and the class of models relevant to describe the ground state. However, the greatest challenge to reach firm conclusions about the low T kagome physics is still to discriminate between what belongs to kagome Cu's and what is the counterpart induced by defects. We have mapped out in detail the latter contribution and could then isolate the 17O NMR spectral signature of kagome Cu's. Neither in our shift measurements nor in our relaxation studies, do we find any hint of a gap. On the contrary, we conclude that the susceptibility is finite and independent of the field in the range 2.6 - 12 Teslas [2]. Insights on the defect physics is also gained from recent high field ESR measurements on our samples [3]. 2- In [NH4]2[C7H14N][V7O6F18], the V4+ ions (d1) form a unique S = ½ breathing kagome lattice which consists of alternating equilateral triangles, preserving the full frustration of the isotropic model and the spin liquid ground state [4]. Combining NMR measurement of the local susceptibility and state-of-the-art series expansion analysis, we could evaluate the ratio $J\Delta/ J\nabla \sim 0.55$ for the interactions of the two sets of triangles. In line with recent theoretical results from variational methods and DMRG, we found that the spinon excitations are gapless and lead to a metallic-like low T heat capacity in this strong insulator. This experimental study should trigger novel theory approaches of the kagome problem through a J’-> J limit.

**References**

[1] A. Olariu, Phys. Rev. Lett. (2008) ; M. Fu et al., Science 350, 655 (2015) ;

[2] P. Mendels et al., in preparation (2018).

[3] A. Zorko et al., Phys. Rev. Lett. 118, 117202 (2017).

[4] L. Clark et al., Phys. Rev. Lett. 110, 207208 (2013) ; J.C. Orain et al., Phys. Rev. Lett., 118, 237203 (2017).

2

# Hidden spin currents in doped Mott antiferromagnets

ZhengYu Weng

*Institute for Advanced Study, Tsinghua University*

We study the nature of doped holes in the Mott insulator by using exact diagonalization and density matrix renormalization group numerical methods. Persistent spin current pattern around a doped hole is found to be concomitant with a nonzero total momentum or angular momentum in the ground state, indicating a novel composite structure of a doped hole. Such anomaly persists for the odd numbers of holes, but the spin current, ground state degeneracy, and charge/spin modulations completely disappear for even numbers of holes, with the ground state exhibiting a d-wave symmetry. An understanding of the spin current is given by a wavefunction description for the one-hole ground state, which reproduces the DMRG/ED results excellently by variational Monte Carlo calculation. Implications to the high-Tc superconductivity and the pseudogap physics will be discussed.

3

# Thermal control of domain-wall excitations in the coupled Ising-chain material $RbCoCl_3$

Bruce Normand
*Paul Scherrer Institute*

*with M. Mena, E. Hirtenlechner, N. Hänni, S. N. E. Ward, R. Bewley, C. Hubig, U. Schollwöck, F. H. L. Essler, K. W. Krämer, D. F. McMorrow and Ch. Rüegg*

We investigate the dynamics of the quantum (S = 1/2) antiferromagnetic Ising spin chains realised in $RbCoCl_3$. This material has two magnetic phase transitions at low temperatures, presenting an ideal opportunity for thermal control of the magnetic order through three different phases, which we exploit to separate the physics of the isolated Ising chain from the physics of the Ising chain in a staggered magnetic field. Neutron spectroscopy measures the two-domain-wall excitations of the system, characterising precisely both the continuum response of the isolated chain and the bound states of chains in three different effective staggered fields at low temperatures.

We develop an extended Matsubara formalism which provides a quantitative description of the neutron data in all three phases. We use cluster-heat-bath Monte Carlo simulations to model the magnetic order and the ratios of chain types in the ordered phases. By finite-temperature DMRG calculations we benchmark the Matsubara fitting parameters and gauge the broadening effects of thermal domain walls on the isolated-chain response. The Matsubara framework allows us to estimate the broadening effects of the increasingly random chain environment at higher temperatures, and hence to reproduce the spectral features measured in all three phases, providing a complete understanding of the multi-faceted Ising physics of $RbCoCl_3$.

4

## Mapping the XY ferromagnet in d=2+1 onto electrodynamics

Oleg Tchernyshyov
*Johns Hopkins, Baltimore*

Theory of the Kosterlitz-Thouless transition relies on a mapping of the XY ferromagnet in d=2 onto the classical theory of electrostatics, in which a vortex behaves like a particle whose electric equal to its winding number $n$. Thus vortices interact via a Coulomb potential with a logarithmic dependence on the distance. We extend the analogy to the dynamical phenomena in d=2+1 spacetime. At low energies, the theory resembles regular electrodynamics with a background magnetic field. In addition to the electric charge, a vortex carries a magnetic flux proportional to the transverse spin $S_z$ of its core. Braiding two identical vortices yields an extra phase of $2\pi n S_z$. Thus vortices with integer $n S_z$ are bosons and those with half-integer $n S_z$ are fermions.

5

# Confined and Deconfined Fractional Spin Excitations in two-dimensional Mott Insulators: A Spectral Perspective

Jian-Xin Li

*Department of Physics, and National Laboratory of Solid State Microstructure, Nanjing University, Nanjing 210093, China*

In this talk, I will present our recent work on spectral properties of the antiferromagnetic J1-J2 Heisenberg model, based on the extension of the electronic cluster perturbation theory to spin systems by using the mapping between spin-1/2 operators and hard-core bosons [1]. We find that deconfined spin-1/2 spinons beyond the conventional spin-1 magnons have already emerged partially even in the limit J2=0 and develop with J2, exhibiting as a continuum close to (π,0) in the Brillouin zone. In the region near J2=0.5J1, the entire spectrum is characterized by a broad continuum in which all magnons are deconfined into spinons, whose ground state is attributed to a Z2 quantum spin liquid with a help of the variational-Monte-Carlo analysis. The spinon continua are also found in the stripe phase with J2>0.6J1. In addition, I will also show the coexistence of fractional spin excitations and magnons in the spectra of the Kitaev-Γ (off-diagonal) model, which is suggested to describe the spin-orbital Mott insulator α-RuCl3 [2,3].

Reference:

[1] S.L. Yu, W. Wang, Z.Y. Dong, Z.J. Yao, and J.X. Li, arXiv: 1805.07915
[2] W. Wang, Z.Y. Dong, S.L. Yu, and J.X. Li, Phys. Rev. B 96, 115103 (2017)
[3] K.J. Ran, J.H. Wang, W. Wang, Z.Y. Dong, X. Ren, S. Bao, S.C. Li, Z. Ma, Y. Gan, Y.T. Zhang, J.T. Park, G.C. Deng, S. Danilkin, S.L. Yu, J.X. Li, and J.S. Wen Phys. Rev. Lett. 118, 107203 (2017)

6

# SU(3) trimer resonating-valence-bond state on the square lattice

Hong Hao Tu

*Technische Universität Dresden*

I will present our recent study (arXiv:1807.03254) on an SU(3) trimer resonating-valence-bond (tRVB) state with $C_{4v}$ symmetry on the square lattice. We find that this state has a natural projected entangled-pair state (PEPS) representation. By using the PEPS representation, we show that all local correlation functions in the SU(3) tRVB state decay exponentially and, furthermore, the numerically calculated modular S and T matrices establish the existence of $Z_3$ topological order.

9

# Quantum Monte Carlo Study of Random Heisenberg Chains and Dimerized Spin Systems

Dao-Xin Yao

*Sun Yat-Sen University*

We use quantum Monte Carlo method to study the random Heisenberg chains and dimerized spin systems on the square lattice. For the 1D case, we study the random Heisenberg chains with standard Heisenberg couplings and multi-spin couplings. The QMC simulations demonstrate logarithmic corrections to the power-law decaying correlations obtained with the SDRG scheme. In the model with multispin couplings, where the clean system dimerizes spontaneously, random singlets form between spinons localized at domain walls in the presence of disorder. This amorphous valence-bond solid is asymptotically a random-singlet state. The dynamical properties of the random Heisenberg chain is studied by using the stochastic analytic continuation of quantum Monte Carlo results in imaginary time. We investigate the dynamic spin structure factor S(q, ω), which can be probed by inelastic neutron scattering and NMR experiments. For the 2D case, we study the Neel-paramagnetic quantum phase transition in two-dimensional dimerized S=1/2 Heisenberg antiferromagnets using finite-size scaling of quantum Monte Carlo data.We resolve the long standing issue of the role of cubic interactions arising in the bond-operator representation when the dimer pattern lacks a certain symmetry. We find non-monotonic (monotonic) size dependence in the staggered (columnar) dimerized model, where cubic interactions are (are not) present. We conclude that there is an irrelevant field in the staggered model that is not present in the columnar case, but, at variance with previous claims, it is not the leading irrelevant field. Our study highlights the possibility of competing scaling corrections at quantum critical points.

References：

[1] Phys. Rev. B 97, 104424 (2018); Phys. Rev. B 97, 224419 (2018).

[2] ArXiv:1804.01273, submitted to PRL

[3] Phys. Rev. B 96, 094304 (2017).

[4] Phys. Rev. B 94, 174442 (2016).

[5] Phys. Rev. B 90, 104425 (2014).

[6] Phys. Rev. B 82, 172409 (2010).

10

## Topological magnon bands in a highly-interconnected antiferromagnet

Yuan Li

*International Center for Quantum Materials, Peking University, China*

The recent discovery of topological semimetals, which possess distinct electron-band crossing with non-trivial topological characteristics, has stimulated intense research interest. By extending the notion of symmetry-protected band crossing into one of the simplest magnetic groups, namely by including the symmetry of time-reversal followed by space-inversion, we predict the existence of topological magnon-band crossing in three-dimensional (3D) antiferromagnets. The crossing takes on the forms of Dirac points and nodal lines, in the presence and absence, respectively, of the conservation of the total spin along the ordered moments. In a concrete example of a Heisenberg spin model for a "spin-web" compound, we theoretically demonstrate the presence of Dirac magnons over a wide parameter range using the linear spin-wave approximation, and obtain the corresponding topological surface states [1].

Inelastic neutron scattering experiments have then been carried out to detect the bulk magnon-band crossing in a single-crystal sample. The highly interconnected nature of the spin lattice suppresses quantum fluctuations and facilitates our experimental observation, leading to remarkably clean experimental data and very good agreement with spin-wave calculations. The predicted topological band crossing is confirmed [2].

[1] K. Li et al., PRL 119, 247202 (2017).

[2] W. Yao et al., arXiv:1711.00632 (Nature Physics, in press).

11

## Loop braiding statistics with fermionic particles

Chenjie Wang

*City University of Hong Kong*

Three-dimensional topological orders are characterized by the fusion and braiding properties of both particle-like and loop-like excitations. In this talk, I will present some recent progress on loop braiding statistics in the presence of fermionic particles, going beyond previous studies which all focused on the case that particles are bosonic. In particular, I will show that there exist certain types of loop braiding statistics that are allowed only in the the presence of fermionic particles, which result from gauging 3D "intrinsic" fermionic symmetry- protected topological (SPT) phases, i.e., those that do not stem from bosonic SPT phases.

12

# Emergent U(1) Quantum Spin Liquid in Kitaev's Honeycomb Model: Complete Phase Diagram in Titled Magnetic Fields

Ciaran Hickey

*Institute for Theoretical Physics Cologne*

Kitaev's honeycomb model is a remarkable exactly solvable spin-1/2 model, consisting of bond dependent Ising interactions, and with a gapless quantum spin liquid ground state. Even more remarkably such interactions are actually realized in a number of spin-orbit entangled Mott insulators, alongside other more conventional interactions. Here, motivated by the recent surge in interest in the behaviour of these materials in a magnetic field, we map out the complete phase diagram of the pure Kitaev model in tilted magnetic fields. Besides the expected gapped quantum spin liquid at low fields and the trivial polarized state at high fields we report the emergence of a distinct gapless quantum spin liquid at intermediate field strengths. Analyzing a number of static, dynamical, and finite temperature quantities using numerical exact diagonalization techniques, we find strong evidence that this phase exhibits gapless fermions coupled to a massless gauge field resulting in a dense continuum of low-energy states. We discuss its stability in the presence of perturbations, Heisenberg and off-diagonal symmetric exchange interactions, that naturally arise in spin-orbit entangled Mott insulators alongside Kitaev interactions.

13

# Nested Tensor Network Method and its application in Kagome spin liquid

Zhiyuan Xie

*Department of Physics, Renmin University of China*

In the tensor-network framework, the expectation values of two-dimensional quantum states are evaluated by contracting a double-layer tensor network constructed from initial and final tensor-network states. The computational cost of carrying out this contraction is generally very high, which limits the largest bond dimension of tensor-network states that can be accurately studied to a relatively small value. We propose an optimized contraction scheme to solve this problem by mapping the double-layer tensor network onto an intersected single-layer tensor network. This reduces greatly the bond dimensions of local tensors to be contracted and improves dramatically the efficiency and accuracy of the evaluation of expectation values of tensor-network states. It almost doubles the largest bond dimension of tensor-network states whose physical properties can be efficiently and reliably calculated, and it extends significantly the application scope of tensor-network methods.

References: PRB 96, 045128 (2017), PRL 118, 137202 (2017).

15

# In search of non-Abelian chiral spin liquid states on Honeycomb and Kagome lattices

ZhengXin Liu

*Department of physics, Renmin University of China*

It is known that the gapless phase of the Kitaev model on Honeycomb lattice can be gapped out by a magnetic field, resulting in a non-Abelian chiral spin liquid. This motivates the profound research on related materials, such as $\alpha$-RuCl$_3$. The magnetically ordered ground state rules out the possibility of a spin liquid ground state, but with a strong in-plane magnetic field, a disordered state with strong spin fluctuations is observed. To see if non-Abelian spin liquid can be induced by the magnetic field, we study the $K$-$\Gamma$ model on the honeycomb lattice using Variational Monte Carlo (VMC) method. With fixed $K=-1, \Gamma=1.4$, we find a field-induced gapless $U(1)$ spin liquid and a gapped abelian chiral spin liquid phase. The former explained the observed temperature dependence of spin-lattice relaxation rate $1/T_1\sim T^3$ in NMR experiments. Since no non-Abelian spin liquid is found, we proposed a spin-1 model on Kagome lattice to realize the non-abelian phase. By calculating the modular matrices, we verified that the trial ground state obtained from VMC is indeed a non-Abelian spin liquid with Ising type anyonic excitations.

16

# Muon Spin Relaxation Study on recent spin liquid candidates.

Lei Shu

*State Key Laboratory of Surface Physics, Department of Physics, Fudan University*

Quantum spin liquid (QSL) state is a state that spins are highly entangled and frustrated even at absolute zero temperature, which has attracted lots of attentions due to its potential application on quantum information and its relation to the mechanism of high superconductors in recent years. Muon spin relaxation (MuSR) is a low-frequency probe of spin dynamics and is particularly sensitive to slow spin fluctuations; it is therefore ideally suited to studies of long-lived spin correlations in QSL candidates. I will present the results from our recent MuSR experiments on spin liquid candidates: the rare-earth Kagome lattice magnet Tm3Sb3Zn2O14, the triangular antiferromagnet YMgGaO4, and new Kagome material Cu3Zn(OH)6FBr.

20

## Resonating valence bonds and spinon superfluidity in a cavity

Ramachandran Ganesh
*Institute of Mathematical Sciences, Chennai, India*

Resonating valence bond (RVB) states are a class of quantum many-body wavefunctions that were first studied in organic chemistry. They play a key role in modern condensed physics as the source of ideas such as topological order. We propose a scheme to synthesize RVB states in cavity-based experiments using the notion of wavefunction collapse. We consider a cavity QED setup with two-level atoms coupled to a common photon mode. In the lossy cavity limit, this can be configured as a Stern-Gerlach experiment wherein the emission of photons is measured. This collapses the wavefunction of the two-level atoms onto a class of RVB states. We show that this naturally gives rise to a superconductor-like phase with Cooper-like pairs of 'spinons' (unpaired spins). We also demonstrate an elegant quantum phase transition from 'darkness' (trapping of photons within the cavity due to quantum interference) to 'light' (emission of photons from the cavity).

21

# Multicritical Fermi surface topological transitions and its experimental signatures in $Sr_3Ru_2O_7$

Joseph Betouras

*Loughborough University*

We will review recent progress on the understanding of the implications of Fermi surface topological transitions (Lifshitz) on the physics of correlated electron systems. The focus then will be on the theoretical framework, supported by experimental evidence for a Lifshitz transition in the ultra-clean layered perovskite metal Sr3Ru2O7. Strong power-law dependence of the density of states on energy, associated to the topological transition, in addition to other main features of the Fermi surface and the strong interactions, lead to novel physics. As a consequence, many yet unexplained properties such as phase formation and thermodynamics can be understood.

22

# Tuning magnetic order and quantum transport in magnetic topological insulators

Yayu Wang

*Department of Physics, Tsinghua University, Beijing 100084, China*

Magnetic topological insulators (TIs) are fascinating material systems for realizing exotic quantum effects and novel device functionalities. In this talk, we present transport studies on magnetically doped TI thin films grown by molecular beam epitaxy. We found a variety of interesting magnetic phenomena and quantum transport properties by varying the magnetic dopants, film thickness, applied electric field, and degree of disorderness. In Cr doped $Bi_2(Se,Te)_3$ near a topological quantum critical point, we found a gate-tuned ferromagnetic to paramagnetic phase transition. We propose that the most likely mechanism is the Stark effect induced electronic energy level shift, which causes a topological quantum phase transition followed by magnetic phase transition. In Mn doped Bi2Te3, we observe pronounced topological Hall effect only at a specific film thickness at the dimensional crossover regime. We propose that this is due to the coupling between the top and bottom surface states, which stabilizes the magnetic skyrmion structure. More recently, we found that with increasing degree of disorderness, there is a transition from the quantum anomalous Hall liquid phase to quantum anomalous Hall insulator phase. We propose a model considering the transmission between the chiral edge states at the domain boundaries to explain this phenomenon, as well as some other puzzles regarding the quantum anomalous Hall effect.

23

# Spin-Orbit Dimers and Non-Collinear Phases in $d^1$ Cubic Double Perovskites

Romhanyi, Judit[1]; Balents, Leon[2]; Jackeli, George[3, 4]

*1. Theory of Quantum Matter Unit, Okinawa Institute of Science and Technology , Onna-son, Okinawa, Japan.*

*2. University of California, Santa Barbara, Santa Barbara, CA, United States.*

*3. Max Planck Institute for Solid State Research, Stuttgart, Germany.*

*4. Institute for Functional Matter and Quantum Technologies, University of Stuttgart, Stuttgart, Germany.*

Novel quantum phases of matter arising in heavy transition metal compounds due to the strong relativistic spin-orbit coupling have attracted a lot of interest recently. Current experiments on the molybdenum [1-3] and osmium [4-6] based double perovskites, suggest that unusual ordered and disorder quantum states are hosted by these materials.

We formulate and study a microscopic spin-orbital model for a family of cubic double perovskites with d1 ions occupying frustrated fcc sublattice. Relying on variational approaches and a complimentary analytical analysis, we find a rich variety of phases, emerging from the interplay of Hund's coupling and spin-orbit interaction. The phase digram contains non-collinear ordered states, with or without net moments, and, remarkably, a large window of magnetically disordered spin-orbit dimer phase [3].

We discuss the physical origin of the unusual amorphous valence bond state experimentally suggested for Ba2BMoO 6 (B=Y,Lu), and predict possible ordered patterns in Ba2BOsO6 (B=Na,Li) compounds. Additionally, we provide a theoretical background for the available experimental observation in these materials [3].

The proposed physical picture applies to a broad family of heavy transition metal compounds and helps uncovering the origins of magnetism in spin-orbit assisted Mott insulators.

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## Thermodynamic and ground-state properties of a generalized Shastry-Sutherland model for $SrCu_2(BO_3)_2$

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$SrCu_2(BO_3)_2$ is famous for its rich physical properties and as a realization of the two-dimensional spin-1/2 Shastry-Sutherland model. In the latter model, an orthogonal arrangement of dimers gives rise both to an exact dimer ground state and geometric frustration that renders quantitatively reliable results for the low-temperature thermodynamic properties a challenge since, e.g., conventional Quantum-Monte-Carlo (QMC) simulations suffer from a severe minus sign problem. We study a generalized Shastry-Sutherland model that thanks to inclusion of a third-neighbor coupling interpolates to the fully frustrated Heisenberg bilayer. First, we study the ground-state phase diagram using the tensor-network approach iPEPS and find three phases: a dimer phase at small inter-dimer coupling, an antiferromagnetic phase at large interdimer couplings, and a small intermediate plaquette phase at small third-neighbor coupling. Then we apply a recently developed QMC method in the dimer basis and find that the minus sign problem is sufficiently reduced to be able to obtain highly accurate results for the specific heat C and the magnetic susceptibility $\chi$ in a big part of the dimer phase. However, the low-temperature behavior in the parameter regime relevant to $SrCu_2(BO_3)_2$ remains out of reach of the QMC simulations. We therefore further explore the applicability of high-temperature series and exact diagonalization to access this regime.

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# High pressure phases in the Shastry-Sutherland spin system $SrCu_2(BO_3)_2$

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The two-dimensional coupled dimer spin system $SrCu_2(BO_3)_2$ is a good realization of the frustrated Shastry-Sutherland model and exhibits a number of fascinating properties, in particular, a series of fractionally quantized magnetization plateaus in high magnetic fields. Recent studies have opened another interesting possibility to explore various phases in the Shastry-Sutherland model and quantum transition among them by applying high pressure and thereby relative strength of changing exchange couplings. I will present $^{11}B$ NMR results on $SrCu_2(BO_3)_2$ under high pressure up to 2.8 GPa based on both published (Waki et al. JPSJ 76 (2007) 073710) and unpublished data and discuss implication of our results in relation to other recent experiments and theories.

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## Spin dynamics of magnetically ordered, frustrated quantum pyrochlore magnets

Radu Coldea

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$Yb_2Ti_2O_7$ and $Er_2Ti_2O_7$ are effective spin-1/2 frustrated magnets on the three-dimensional pyrochlore lattice displaying distinct types of magnetic order in the ground state, ferromagnetic and XY antiferromagnetic order, respectively. Here we report results of single-crystal, high-resolution inelastic neutron scattering measurements to explore the interplay between sharp magnon modes and extended excitation continua, and the evolution of the spin dynamics in applied magnetic field.

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## Emergent phenomena in quantum spin liquid with strong spin-orbit coupling

Yong-Baek Kim

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We discuss possible quantum spin liquid and other novel phases in correlated electron systems with strong spin-orbit coupling.In such systems, various bond-dependent exchange interactions between local moments arise. This phenomenon leads to strong magnetic frustration and paves a way to reach novel quantum spin liquid phases.First, we consider layered Kitaev materials and show that the interlayer coupling may lead to a new kind of Kitaev-type spin liquid. This result is discussed in the context of the newly-discovered hydrogen-intercalated honeycomb iridate, H3LiIr2O6. Secondly, we show that the bond-dependent interactions naturally arise in the pyrochlore systems with f-electron local moments. We apply this idea to the pyrochlore material, Yb2Ti2O7, which has been regarded as an example of the quantum spin ice. It is shown that there exists an alternative explanation of the existing experimental results via the emergence of a different kind of three-dimensional spin liquid.

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# Tensor network state approach to quantum topological phase transitions in two dimension

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Due to the absence of local order parameters, it is a challenging task to characterize two-dimensional quantum topological phase transitions between intrinsic topological ordered phases. Based on a tensor-network wave function with a tuning parameter λ for the Z2 symmetry protected topological phases, we construct the corresponding wave function describing both toric code and double semion phases by introducing $Z_2$ gauge fields into the tensor network. By calculating the correlation length as a function of λ from the transfer operator of the wave function norm, we map out the whole phase diagram and identify three quantum critical points (QCPs) at λ=0, ±1.73, respectively. The first QCP separates the toric code and double semion phases, while later two QCPs describe the phase transitions from either toric code or double semion to the symmetry breaking phase. By mapping this tensor-network wave function norm at these QCPs into classical statistics models, we find that λ=±1.73 correspond to the eight-vertex model while λ=0 becomes the six-vertex model. Then we further analyze the full eigenvalue spectra of the transfer operators at these three QCPs, and find that the underlying theories of these QCPs belong to two spatial dimensional conformal field theories with topological anionic excitations. However, the transfer operator at λ=0 QCP has emergent symmetries from matrix product operator (MPO), and the insertion of MPOs will change the quantum numbers of primary fields from integers to half integers.

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# Symmetry-protected topological phases with broken parity in cold fermions in a double-well optical lattice and related models

Keisuke Totsuka

*Yukawa Institute*

Symmetry-protected topological (SPT) phases accompanied by spontaneously broken symmetries are interesting in their own right. In this talk, I will show that an interesting class of SPT phases that spontaneously break parity symmetry can be realized in SU(N) cold fermions loaded in a double-well optical lattice. I then point out an interesting connection of the system to a two-leg SU(N) "spin" ladder and map out the phases of the latter with the use of various methods.

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## Disguised antiferromagnetic order in a two-dimensional quasicrystal

Hirokazu Tsunetsugu

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Antiferromagnets with complicated crystal structure often exhibit a novel phase or exotic spatial pattern in their ordered phases. Quasicrystals are materials with exquisite structure, and the Penrose lattice is the most famous example in two dimensions. We have studied the magnetic order in the ground state of the half-filled Hubbard model on this lattice, and found that the order is antiferro type with disguised spatial pattern, particularly in the weak coupling region. This reflects the quasi-periodicity and self-similarity of the crystal structure. This study is a collaboration with Akihisa Koga at Tokyo Institute of Technology.

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## Interplay between magnetism and superconductivity in Cr- and Mn- based materials

Jianlin Luo

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Transition-metal oxides or pnictides are in rich of novel and intriguing electronic behaviors due to multiple quantum orders and competing phenomena. Among the different electronic states, the emergence of superconductivity in the vicinity of magnetism is at the heart of the rich physics. In this talk, I will present the observation of unconventional superconductivity in vicinity of helical magnetic order in CrAs and MnP via the application of external high pressure. In addition, quantum criticality and non-Fermi liquid behavior are observed in CrAs and CrAs1-xPx, which we interpret as originating from a nearly second-order magnetic quantum phase transition that is concomitant with a first-order structural transition.

In collaboration with Jinguang Cheng, Wei Wu, Kazuyuki Matsubayashi, Fukun Lin, Yoshiya Uwatoko, Rong Yi, and Qimiao Si.

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# Study of 2D critical phenomena and the doped Shastry-Sutherland model with iPEPS

Philippe Corboz

*Universiteit van Amsterdam*

In recent years tensor network methods have become very powerful tools for the study of 2D frustrated magnets. In this talk I report on two recent advances with infinite projected entangled pair states (iPEPS) - a 2D tensor network ansatz for ground states in the thermodynamic limit where the accuracy can be systematically controlled by the bond dimension D of the tensors.

In the first part I will show how iPEPS can be used to accurately study 2D quantum critical phenomena. The main idea is that in the case of a Lorentz invariant critical point, the bond dimension D induces a finite effective correlation length which, in the vicinity of a quantum critical point, acts as a cutoff on the exact, diverging correlation length, similarly to a finite system size. We can then use this to perform a finite correlation length scaling analysis to extract critical couplings and universal critical exponents in a systematic way, similarly as in a conventional finite-size scaling approach. This idea also allows us to obtain accurate estimates of order parameters in gapless systems.

In the second part I will focus on Mg-doped SrCu2(BO3)2 in high magnetic fields, for which experiments revealed intriguing anomalies in the magnetization process that are absent in the undoped case. I will show how iPEPS simulations with large unit cells (up to 288 sites which are periodically repeated on the infinite lattice) helped to obtain an understanding of the nature of these anomalies. While the lower-field anomalies appear due to the presence of local impurity pairs, the two higher-field features can be associated to the first appearance of localized bound states and triplets, respectively.

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# (H,T) phase diagram and candidate spin-liquid phase of a purely 2D triangular lattice antiferromagnet $Ba_8CoNb_6O_{24}$

Weiqiang Yu

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The purely 2D triangular lattice antiferromagnet is a challenge for theorists, and also hard to be realized in materials. Here I report that Ba8CoNb6O24, with a very large interlayer spacing, presents a system whose Co2+ ions have an effective spin 1/2 and construct a regular triangular-lattice antiferromagnet (TLAFM), with a purely two-dimensional character. We find strong low-energy spin fluctuations and no magnetic ordering, but a diverging correlation length down to 0.1 K, indicating a Mermin-Wagner trend toward zero-temperature order. We establish the (H,T) phase diagram, mapping in detail the quantum fluctuation corrections to the available theoretical analysis. These include a strong upshift in field of the maximum ordering temperature, qualitative changes to both low- and high-field phase boundaries, and an ordered regime apparently dominated by the collinear "up-up-down" state. Below 0.1 K, however, our low-field measurements show an unexpected magnetically disordered state, which is a candidate quantum spin liquid.

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# Unusual RG flow and scaling theory of frustrated quantum magnets with quenched disorder

Itamar Kimchi

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Several longstanding problems in quantum magnetism concern quenched disorder. In this talk we will discuss the role of random exchange energies in spin-1/2 magnets where magnetic frustration promotes the formation of entangled valence bonds. This includes a theory for 2d valence-bond solids subject to weak bond randomness as well as extensions to stronger disorder regimes relevant to spin liquids. In both cases, we find that bond-randomness disorder nucleates topological defects that carry spin-1/2 moments, thereby renormalizing the lattice into a strongly random spin network with interesting low-energy excitations. Motivated by these results we conjecture Lieb-Schultz-Mattis-like restrictions for disordered magnets with spin-1/2 per statistical unit cell. The conjecture is proved in 1d. I will then turn to experimental connections: most strikingly, heat capacity measurements on various spin-1/2 magnets -- all described by magnetic frustration and quenched disorder but with no other common relation -- nevertheless show quasi-universal one-parameter data collapse of C[H,T] in a magnetic field. I will argue that this data collapse and its particular scaling function can be understood in terms of the theory as an emergent network of long range valence bonds at low energies.

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# Experimental Investigation of a Quantum Spin Liquid based on a breathing kagome bilayer lattice

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$Ca_{10}Cr_7O_{28}$ is a new quantum spin liquid where the magnetic Cr5+ ions (S-1/2) form breathing Kagome bilayers. Both kagome layers consist of alternating ferromagnetic and antiferromagnetic corner-sharing triangles and the two layers are stacked so that the ferromagnetic triangles lie on top of antiferromagnetic triangles and vice versa. Previous measurements revealed the absence of long-range magnetic order and the presence of persistent spin dynamics in the ground state. Here we present a detailed exploration of the ground state and excitations using magnetisation, heat capacity, thermal conductivity and inelastic neutron scattering. The heat capacity and thermal conductivity are linear in temperature suggesting the presence of a gapless spinon Fermi surface. The excitations are diffuse revealing the presence of spinon continuua, and they form a distinct pattern that evolves gradually with energy. The data is compared to theoretical models for the spinon Fermi surface. Together these results provide strong evidence that $Ca_{10}Cr_7O_{28}$ is a gapless Z2 quantum spin liquid.

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# Ground State of the Quantum S=1/2 Honeycomb Gamma model

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We investigate the quantum spin S=1/2 Gamma model on a honeycomb lattice by using three different numerical methods, including DMRG, VUMPS, and iPEPS. All three methods show that the ground state of the Gamma model is a magnetic Zigzag ordered state, rather than a spin liquid state. Thus the quantum spin S=1/2 Gamma model is extremely different from its classical counterpart, which was thought as a classical spin liquid with macroscopic ground-state degeneracy.

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# Evidence for a $Z_2$ topological ordered quantum spin liquid in $Cu_3Zn(OH)_6FBr$

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A quantum spin liquid with a $Z_2$ topological order has long been thought to be important for the application of quantum computing and may be related to high-temperature superconductivity. While a two-dimensional kagome antiferromagnet may host such a state, strong experimental evidence is still lacking. Here we show that $Cu_3Zn(OH)_6FBr$ exhibits gapped spin continuum at low temperature and is not magnetically ordered down to 20 mili Kelvin. The spin triplet gap value is about twice of the spinon gap value reported previously. Our results provide firm ground for the existence of spin-1/2 spinon excitations in $Cu_3Zn(OH)_6FBr$, whose ground state is thus a gapped quantum spin liquid with $Z_2$ topological order.

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## Random-Singlet Phase in Disordered Two-Dimensional Quantum Magnets

Wen An Guo

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Materials always contain some amount of disorder (randomness) or impurities,which can significantly alter their properties. While in some cases it is desirable to minimize the amount of disorder, in other cases disorder can be important to achieve certain material properties. Here we discuss a class of insulating quantum magnets in which disorder can induce a completely new kind of state, the properties of which were previously not known. We do this by large-scale computer simulations of a model system designed to generate the state in question - the random singlet state - while at the same time being amenable to the most efficient simulation algorithms. Our results show that, upon introduction of disorder, an antiferromagnet can undergo a phase transition at a critical point into the RS state, provided that there are some interactions in the system that favor correlation of singlet pairs (dimerization). The RS state, which is likely realized in many materials that have so far been classified as 'disordered spin liquids', exhibit power-law scaling properties of experimentally measurable properties.

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## Out-of-equilibrium dynamics of quantum spin chain

Gregoire Misguich

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We study the dynamics of a quantum spin chain (S=1/2 XXZ model), which is prepared at t=0 in a domain-wall initial sate, where the spins are initially pointing up on the left half-line and down on the right half-line. Using extensive time-dependent DMRG simulations we analyze the evolution of the magnetization profile, as a function of the anisotropy parameter (Delta) the Hamiltonian. These numerical results are compared with the predictions of a recently developed hydrodynamics approach [Castro-Alvaredo et al., PRX 2016 and Bertini et al. PRL 2016], which generalizes the conventional hydrodynamics to integrable one-dimensional quantum systems. For this domain wall problem the situation of the isotropic Heisenberg model (Delta=1) is particularly interesting and not yet fully understood, and at this point our data suggest a diffusive behavior [Misguich, Mallick & Krapivksy, PRB 2017].

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## The quantum effects on the spin excitations of the triangular-lattice antiferromagnets

Jie Ma

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The quantum fluctuation could interfere the spin, electron, lattice and orbitals, especially for the low-dimensional frustrated system with small spin moment (S=1/2 or 1) , and host exotic ground states such as nematic spin-state and chiral liquid phase. One striking example of these quantum phenomena is the transition from a non-collinear 120° spin structure in zero magnetic field into a collinear up-up-down (uud) state in a finite range of applied magnetic field, where the magnetization displays a plateau at one-third of its saturation value M=Ms/3. Although there is an enormous theoretical activity on the origin of those quantum states, the experimental investigation of the spin excitations is still limited. Ba3CoSb2O9 is the first spin-1/2 equilateral TLAF vanishing Dzyaloshinskii-Moriya. The magnetic Co2+ layers are well separated by the non-magnetic clusters of the Sb2O9 bioctahedra and Ba2+ ions. We have performed elastic and inelastic neutron scattering on this spatially-isotropic antiferromagnet, and observed strong quantum effects in the system. Through detailed comparisons with the linear and nonlinear spin-wave theories, we point out that the large-S approximation is inadequate to explain our experimental observation. Moreover, we have extended the work to the other TLAFs of the triple- or multi-perovskite compounds with S=1 and 5/2.

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# Spin nematics in spin-1/2 antiferromagnets next to spin singlet phase

Chisa Hotta

Yuto Yokoyama and Chisa Hotta,

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Spin nematics in spin-1/2 systems is known to appear mostly either at high fields or in the vicinity of a ferromagnetic phase. There, the two magnon excitations in those fully polarized nearby phases form bound states and condense and form a quadrupolar order[1]. We propose instead a different mechanism to have spin nematics in the vicinity of spin singlet phase -- a trivial phase of spin-1/2 antiferromagnet based on a dimer structure[2]. We show that the ring exchange interaction that connect pairs of spins belonging to different dimers generate a spin-1 biquadratic interaction term, which is responsible for the emergent spin nematics. The Bose Einstein condensate(BEC) of SU(2) triplets is also observed {\it without} a magnetic field, which is the one that could be discriminated from the magnon BEC, and further, the coexistence of BEC and spin nematics is observed in this kind of simple toy model.

[1] see for example, N. Shannon, T. Momoi, and P. Sindzingre, Phys. Rev. Lett. 96, 027213 (2006).

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## Imaginary time crystal

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Understanding a quantum system embedded in an environment is not only of practical significance in quantum device design, but also closely relevant to fundamental questions such as quantum-to-classic transitions, decoherence mechanism, and quantum measurement. The situation is further complicated but more interesting if the open quantum system itself is an interacting many-body system, where interplay between the environment and quantum many-body effect may give rise to novel quantum phases and phase transitions that absent in their closed counterpart. In this paper, we perform a numerical exact Quantum Monte Carlo simulation and study an open quantum many-body system with onsite bath-induced retarded interaction. A novel quantum phase of matter is proposed. One of the most intriguing properties of this phase is the translational symmetries in both space and imaginary time are spontaneously broken, which provides new possibilities of spontaneous symmetry breaking in quantum matter.

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## Ground state degeneracy in quantum spin systems protected by crystal symmetries

Yang Qi

*Fudan University*

We develop a no-go theorem for two-dimensional bosonic systems with crystal symmetries: if there is a half-integer spin at a rotation center, where the point-group symmetry is $\mathbb{D}2,4,6$, such a system must have a ground-state degeneracy protected by the crystal symmetry. Such a degeneracy indicates either a broken-symmetry state or a unconventional state of matter. Comparing to the Lieb-Schultz-Mattis Theorem, our result counts the spin at each rotation center, instead of the total spin per unit cell, and therefore also applies to certain systems with an even number of half-integer spins per unit cell.

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## Ground state phase diagram of square lattice J1-J2 and J1-J3 Antiferromagnetic Heisenberg model

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We use DMRG method to calculate several low energy eigenvectors of the frustrated S = 1/2 square-lattice J1-J2 Heisenberg model on $2L \times L$ cylinders with $L \leq 10$. In the nonmagnetic phase, we find the lowest excitation is a singlet. This state together with the ground state form a quasi-degenerate ground state manifold with properties that are consistent with a columnar valence bond solid (VBS) state. Through explicitly calculation of ground states quantum numbers for lattice translation and reflection operators in the periodic direction, we find that they fully match that of a dimerized spin chain. Further measurement of domain wall energy of the ground state on an odd length (in the open boundary direction) cylinder rules out the possiblity of plaquette VBS state. Thus we unambiguously nail down the nature of the nonmagnetic state in the $J1 - J2$ antiferromagnet. The same calculation on the square lattice $J1 - J3$ model tells a plaquette VBS phase, providing good comparison to the columnar nature in the $J1 - J2$ model.

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# Non-equilibrium control of the effective free energy landscape in rustrated magnets

Yuan Wan

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Geometrically frustrated magnets often possess accidentally degenerate round states at zero temperature. At low temperature, thermal luctuations lift the accidental degeneracy and tend to stabilize round states with maximal entropy. This phenomenon, known as “order y disorder”, underlines the fluctuation contribution to the free nergy landscape in frustrated magnets.

In this talk, I show that one can control such free energy landscape n a non-equilibrium setting. In a frustrated magnet with precessional ynamics, the system’s slow drift motion within the degenerate ground tate manifold is governed by the fast modes out of the manifold.Exciting these fast modes generates a tuneable effective free energy andscape with minima located at thermodynamically unstable portions f the ground state manifold. I demonstrate this phenomenon on yrochlore XY antiferromagnet and triangular XY antiferromagnet, where hort magnetic field pulse and/or AC magnetic field are sufficient to nduce such non-equilibrium landscape.

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# Electronic dichotomy in the geometrically frustrated pyrochlore ruthenates

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One challenging problem in strongly correlated electron systems is to understand the electronic behaviors near the localized to itinerant crossover, which lie in the heart of many exotic phenomena such as unconventional superconductivity, metal-insulator transition, and quantum criticality. The Ru5+ pyrochlore oxides A2Ru2O7 (A = Ca, Cd, Hg) with divalent A2+ cation comprise such a system that the Ru-4d3 electrons acquire both characters of itinerancy and localization. In addition, the magnetic Ru5+ ions that are situated on the vertices of a corner-shared tetrahedral lattice are subjected to strong geometrical frustration for antiferromagnetic interactions. As such, these Ru5+-pyrochlore oxides offer an important paradigm for studying the exotic physics of correlated electrons in the presence of both electronic dichotomy and geometrical frustration. In this talk, I will first review the physical properties and distinct ground states of these compounds [1-5], highlighting a peculiar antiferromagnetic metallic state realized in the Cd2Ru2O7. Then, I will present our recent experimental investigations on its electronic behaviors in response to hydrostatic pressure and isovalent substitutions [6-7].

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## Nematic Liquid Phase in a Frustrated Spin-1 System on the Square Lattice

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Competing interactions in quantum spin systems promote a variety of unusual phases. An important example is the frustrated spin-1 model on the square lattice with the nearest-neighbor bilinear (J1) and biquadratic (K1) interactions, which has an enlarged SU(3) symmetry at K1 = J1. We find evidence for a nematic spin liquid phase for a range of K1/J1 near the SU(3)-symmetric point, based on the linear flavor-wave theory (LFWT) and the density matrix renormalization group (DMRG) method. This phase displays no spin dipolar or quadrupolar order, preserves translational symmetry but spontaneously breaks C4 lattice rotational symmetry, and possesses fluctuations peaked at the wavevector (π, 2π/3). The excitation spectrum appears gapless, and the nematic order is attributed to the dominant (π, 2π/3) fluctuations. Our results provide a novel mechanism for electronic nematic order and, more generally, open up a new avenue to explore frustration-induced exotic ground states.

# Low-temperature heat transport of $R_2Ti_2O_7$ (R = rare earth) single crystals

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The rare-earth titanates $R_2Ti_2O_7$ (R = rare earth) are one of the families with three-dimensional spin frustration. These materials have pyrochlore crystal structure, in which the magnetic rare-earth ions form a network of corner-sharing tetrahedra and are prone to a high degree of geometric frustration. Due to the differences in the nearest-neighboring exchange, dipolar interaction, and crystal-field effect for different rare-earth ions, $R_2Ti_2O_7$ can exhibit different exotic ground states, including spin ice, spin liquid, and order by disorder, etc. In this work, we study the low-temperature heat transport of several $R_2Ti_2O_7$ compounds, with R = Dy, Tb, Yb, Gd, and Er, to probe the role of magnetic excitations and discuss the spin-phonon coupling in these materials.

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## Quantum Monte Carlo in the Spin-Dimer Basis

Stefan Wessel

**S. Wessel**, J. Stapmanns, A. Honecker, P. Corboz, B. Normand and F. Mila

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We present a quantum Monte Carlo scheme for the simulation of frustrated dimerized quantum magnets that allows us to reduce or even eliminate the spin-problem for several specific dimerized quantum spin systems. We discuss in particular its application to the thermal properties of the spin-1/2 Heisenberg model on the fully frustrated two-leg ladder and the fully frustrated square lattice model. At zero temperature for the later model, a discontinuous quantum phase transition separates an inter-layer singlet phase from an antiferromagnetic ground state formed by inter-layer triplets. We show that this discontinuous transition extends up to finite temperatures and terminates in a quantum critical point. We identify this critical point to belong to the Ising universality class, even though long-range order is absent at finite temperatures. We furthermore trace the discontinuous quantum phase transitions between the fully frustrated and the unfrustrated bilayer model using tensor network methods. In particular, we identify a quantum critical end point that terminates the quantum critical line originating from the critical point of the unfrustrated bilayer system on the discontinuous transition line.

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## A new effective gauge field theory of quantum spin liquids

Tao Li

*Renmin University, China*

Effective gauge theories based on slave particle construction are widely used in the study of strongly correlated electron systems such as the quantum spin liquids, high-Tc superconductors, and fractional quantum Hall systems, in which emergent gauge field and fractionalized excitations play a central role in the low energy physics. A long standing issue in such effective gauge theories is the fate of the slave particle in the background of strongly fluctuating gauge field and the relation between the slave particles and the physical fractionalized excitations. Here I show that the conventional Gaussian effective gauge theory of the quantum spin liquids is unreliable. In particular, the T^{2/3} specific heat anomaly predicted by the Gaussian effective gauge theory for a gapless U(1) spin liquid with a large spinon Fermi surface is actually an artifact of the Gaussian approximation. A new approach to derive the correct low energy effective theory of the quantum spin liquids is established, which will find broad application in the study of other strongly correlated electron systems. At the same time, an unified mechanism for spin fractionalization in one and two dimensional spin liquids is proposed based on projective construction of fractionalized excitations.

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# Topological Defects in the Frustrated Optical Lattice

Xuefeng Zhang

*Chongqing University*

We analyzed the repulsive particles in the frustrated optical lattice. For the triangular lattice, when introducing the spatial anisotropy, the bosonic domain walls are excited. Such topological defects can continuously change the crystal structure, so that the exotic incommensurate supersolid is observed [1]. Similar phenomena can also be found in the kagome optical lattice. When choosing cylindrical boundary condition, we found a novel edge liquid phase with fractional charges (spinons) linked by quantum strings (effective gauge field) [2]..

Reference:

[1] X.-F. Zhang, S.-J. Hu, A. Pelster, and S. Eggert, Phys. Rev. Lett. 117, 193201 (2016)

[2] X.-F. Zhang and S. Eggert, Phys. Rev. Lett. 111, 147201 (2013)

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## Understanding disorder-induced phases in dipolar spin ice

Arnab Sen

*Indian Association for the Cultivation of Science*

Spin liquids, despite their apparently featureless ground states, are exotic magnetic states which host fractionalised excitations and emergent gauge fields. Interestingly, quenched disorder can nucleate defects with unusual properties and thus reveal the hidden collective excitations of such states. In this talk, I will explain how disorder affects the physics of a prototypical frustrated magnet, dipolar spin ice, both at high and low temperatures and in fact leads to a new phase at low temperature, a "topological spin glass", which shows signatures of both spin liquidity and glassiness. I will also describe a new cluster Monte Carlo algorithm that allows us to study the continuous phase transition to the topological spin glass and reliably extract the critical temperature and exponents.

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# Non-Abelian Moore-Read chiral spin liquid in a frustrated Heisenberg antiferromagnet

Didier Poilblanc

Ji-Yao Chen, Laurens Vanderstraeten, Sylvain Capponi, Didier Poilblanc

*Université de Toulouse III Paul Sabatier*

Abelian and non-Abelian topological phases exhibiting protected chiral edge modes are ubiquitous in the realm of the Fractional Quantum Hall (FQH) effect. Here, we investigate a frustrated spin-1 Hamiltonian on the square lattice which could, potentially, host the spin liquid analog of the (bosonic) non-Abelian Moore-Read FQH state, as suggested by Exact Diagonalisation of small clusters. Using families of fully SU(2)-spin symmetric and translationally invariant chiral Projected Entangled Pair States (PEPS), variational energy optimization is performed using infinite-PEPS methods, providing good agreement with Density Matrix Renormalisation Group (DMRG) results. A careful analysis of the bulk spin-spin and dimer-dimer correlation functions in the optimized spin liquid suggests that they exhibit long-range `gossamer tails'. We argue these tails are finite-D artifacts of the chiral PEPS. From the investigation of the Entanglement Spectrum, we observe sharply defined chiral edge modes following the prediction of the SU(2)2 Wess-Zumino-Witten theory and exhibiting a Conformal Field Theory (CFT) central charge c=3/2, as expected for a Moore-Read chiral spin liquid.

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# Finite Correlation Length Scaling in Lorentz-Invariant Gapless iPEPS Wave Functions

Andreas Laeuchli

*Universität Innsbruck, Australia*

It is an open question how well tensor network states in the form of an infinite projected entangled pair states (iPEPS) tensor network can approximate gapless quantum states of matter. In this talk we address this issue for two different physical scenarios: i) a conformally invariant (2+1)d quantum critical point in the incarnation of the transverse field Ising model on the square lattice and ii) spontaneously broken continuous symmetries with gapless Goldstone modes exemplified by the S=1/2 antiferromagnetic Heisenberg and XY models on the square lattice. We find that the energetically best wave functions display {\em finite} correlation lengths and we introduce a powerful finite correlation length scaling framework for the analysis of such finite-D iPEPS states. The framework is important i) to understand the mild limitations of the finite-D iPEPS manifold in representing Lorentz-invariant, gapless many body quantum states and ii) to put forward a practical scheme in which the finite correlation length ξ(D) combined with field theory inspired formulae can be used to extrapolate the data to infinite correlation length, i.e. to the thermodynamic limit. The finite correlation length scaling framework opens the way for further exploration of quantum matter with an (expected) Lorentz-invariant, massless low-energy description, with many applications ranging from condensed matter to high-energy physics.

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# Spin liquids, spin nematics, and valence-bond crystal phases on the pyrochlore lattice

Yasir Iqbal

*Indian Institute of Technology Madras, Chennai, India*

We investigate the quantum Heisenberg and XXZ models on the pyrochlore lattice for a generic spin-S, and competing longer-range interactions. By employing the pseudo fermion functional renormalization group (PFFRG) method, we find in the Heisenberg model, for S=1/2 and S=1, an extended quantum spin liquid phase which is shown to be robust against the introduction of breathing anisotropy and dimerization. The effects of temperature, quantum fluctuations, breathing anisotropies, and further neighbor couplings on the nature of the scattering profile, in particular, the pinch points are studied. We present, for the first time, the complete phase diagram of the frustrated quantum XXZ model, the minimal model for quantum spin ice. In particular, for spin-1/2, we find a spin-nematic phase, a quantum spin liquid, and finally, a planar ferromagnet for the unfrustrated regime, where we benchmark with known Quantum Monte Carlo results.

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## Kagome Physics: Recent Advances

Gang Su

*University of Chinese Academy of Sciences*

Spin liquids are exotic and emergent phenomena in interacting quantum electrons and spins, which have attracted much attention in recent decades, as they are related to high temperature superconductivity, topological quantum computation, quantum phase transition, topological matters, and other intriguing physics. Distinct spin liquid phases are characterized by their gapful or gapless excitation nature and various topological orders. Possible candidates of spin liquid may come from frustrated quantum spins on checkerboard lattice, kagome lattice and pyrochlore structure, etc. Among others, kagome Heisenberg antiferromagnets are the most studied systems both theoretically and experimentally in this area, but ambiguities still remain because of the extreme complexity and difficulties in simulations and materials. In this talk, I will give a brief review on recent advances in experiments and theories concerning kagome lattices, and also present our understandings on kagome physics with spin 1/2, 1, and 3/2 based on state-of-the-art tensor network states. The implications are also discussed.

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**Efficient simulation of the dynamics in frustrated spin systems**

Frank Pollmann

*Munich Quantum Center*

Dynamical response functions encode characteristic features of the emergent excitations in frustrated magnets. We introduce a matrix-product state based method to efficiently obtain these dynamical response functions for general two-dimensional lattice Hamiltonians. First, we apply this method to different phases of the Kitaev-Heisenberg model. Here we find significant broad high energy features beyond spin-wave theory even in the ordered phases proximate to spin liquids. This includes the phase with zig-zag order of the type observed in $\alpha$-RuCl3, where we find high energy features like those seen in inelastic neutron scattering experiments. Second, we study the stability of magnon excitations in Heisenberg antiferromagnets.

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# Dynamical structure factor of frustrated spin models: a variational Monte Carlo approach

Federico Becca

*Scuola Internazionale Superiore di Studi Advanzati, Italy*

The spin dynamical structure factor is computed within a variational framework to study frustrated Heisenberg models in one and two dimensions. Starting from Gutzwiller-projected fermionic wave functions, the low-energy spectrum is constructed by considering two-spinon excitations. A benchmark of this approach on the one-dimensional $J_1$-$J_2$ model is considered. Here, an excellent description of both the gapless and gapped (dimerized) phases is obtained, also describing the incommensurate structure for large frustrating ratios $J_2/J_1>0.5$ [1]. In the square lattice, we are able to unveil the dynamical signatures of the transition between the Neel and the (gapless) spin-liquid phases that takes place for $J_2/J_1 \sim 0.45$. In particular, by increasing the frustration, the magnon excitation at ${\bf q}=(\pi,0)$ and $(0,\pi)$ broadens, suggesting the tendency towards a spin fractionalization. In addition, its energy softens, indicating the presence of gapless states at the transition and within the spin-liquid phase. [2]

[1] F. Ferrari, A. Parola, S. Sorella, and F. Becca, submitted.

[2] F. Ferrari and F. Becca, arXiv:1805.09287

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# Selective measurement of intertwined multipolar order and emergent quantum criticality from spin-orbital entanglement in d^8 Mott insulators

Gang Chen

*Fudan University*

In the first part of the talk, we point out a method to detect the presence of hidden order and reveal the underlying structure of the hidden orders from the non-commutative observables. We illustrate this thought from the non-Kramers doublets on the triangular lattice. In the second part of the talk, we explore the competition between spin-orbit coupling and the exchange interaction, and suggest the existence of the quantum criticality from such competition. We apply the idea to the spin-1 diamond lattice antiferromagnet NiRh2O4. We further point out the correspondence between different configuration and suggest the possibility of p-wave superconductivity in the presence of doping on d^8 systems.

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# Z2 invariant for topological magnon insulators

Hosho Katsura

*University of Tokyo*

Recently, there has been growing interest in finding insulating magnon systems with topological properties. However, examples have so far been mostly limited to systems which can be thought of as a magnetic analogue of integer quantum Hall systems. In this talk, I will introduce a new class of insulating magnon systems that are the bosonic counterpart of class AII topological insulators in two dimensions. The systems are characterized by the presence of ``Kramers pairs" of bosons. The magnon band for each Kramers pair carries a Z2 topological invariant defined by the Berry connection and curvature in momentum space. I will demonstrate by example that the Z2 invariant so defined precisely characterizes the presence/absence of helical edge modes.

## Posters List

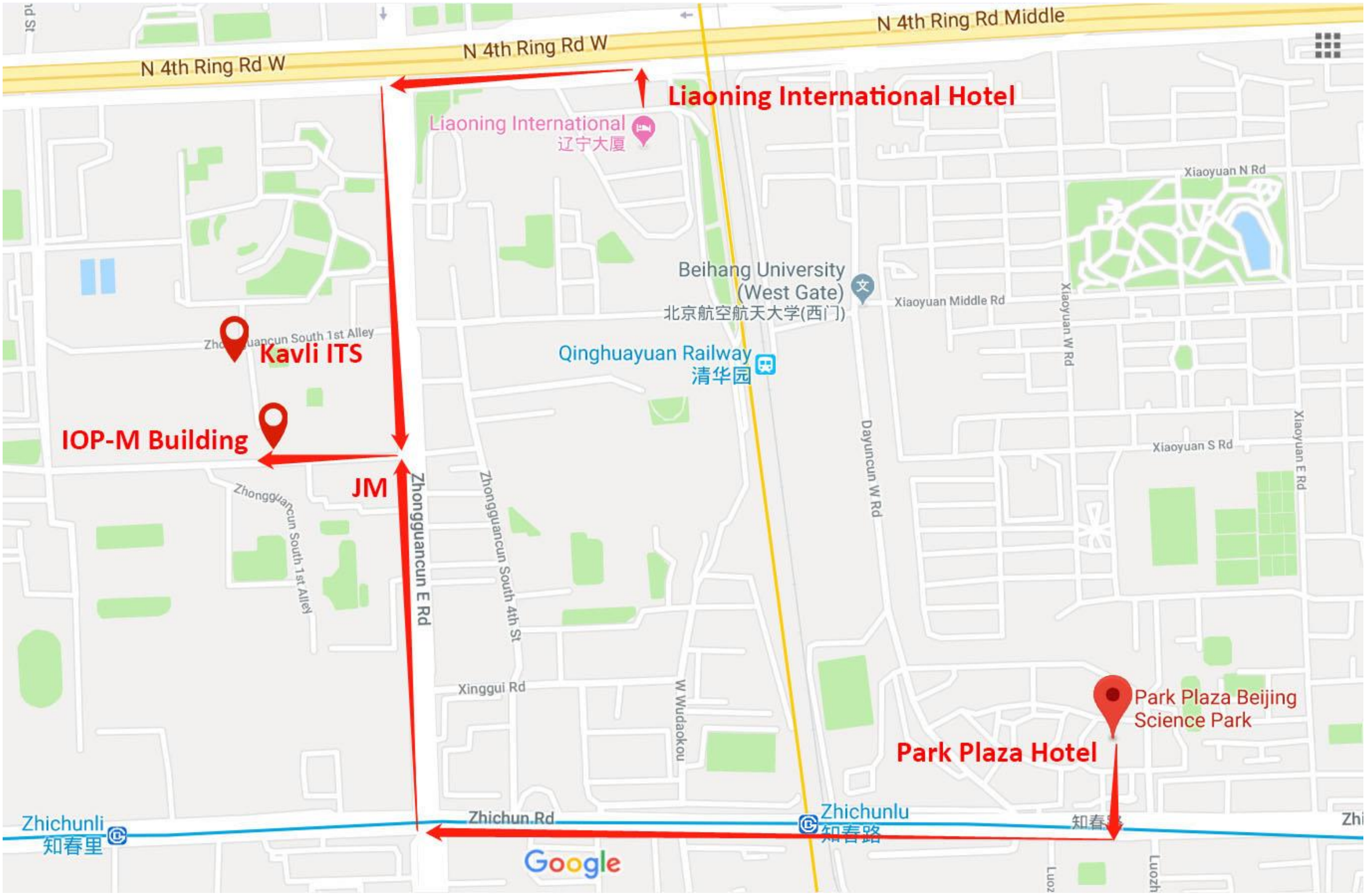
**Note:** Please display your posters at the board and session as indicated below. Please present a two-minute introduction on the posters in the order as below.

| No. | Name | Affiliation | Poster Title |
|---|---|---|---|
| 1 | **Qiaoni Chen** | BNU | "Scaling transformation" of a Three band Periodic Anderson Model |
| 2 | **Shuai Chen** | Tsinghua | Two-hole ground state wavefunction: A non-BCS pairing in a t-J system |
| 3 | **Peng Cheng** | Stanford | (TBA) |
| 4 | **Zili Feng** | IOP, CAS | The Zn doping effect on the anti-ferromagnetism in kagome $Cu_{4-x}Zn_x(OH)_6FBr$ |
| 5 | **Masataka Kawano** | Tokyo | Spin textures, thermal Hall effect and topological edge state in two dimensional antiferromagnets |
| 6 | **Li Liang** | Tsinghua | The role of interstitial hydrogen in $SrCoO_{2.5}$ antiferromagnetic insulator |
| 7 | **Feiye Li** | Fudan | Emergent quantum criticality from spin-orbital entanglement on a diamond lattice antiferromagnet |
| 8 | **Huimei Liu** | MPI Stuttgart | |
| 9 | **Changle Liu** | Fudan | Extended Coulomb liquid of paired hardcore boson model on a pyrochlore lattice |
| 10 | **Zheng Li** | IOP, CAS | Magnetic Phase Diagram of $Cu_{4-x}Zn_x(OH)_6FBr$ |
| 11 | **Nvsen Ma** | IOP, CAS | Dynamical Signature of Fractionalization at the Deconfined Quantum Critical Point |
| 12 | **Yao Shen** | Fudan | Discovery of intertwined multipolar order in the triangular-lattice magnet $TmMgGaO_4$ |
| 13 | **Guangyu Sun** | IOP, CAS | Dynamical Signature of Symmetry Fractionalization in Frustrated Magnets |
| 14 | **Jun Takahashi** | IOP, CAS | Studying emergent symmetry at a first-order transition with a simple model |
| 15 | **Jiucai Wang** | | Phase diagram of ferromagnetic K-Γ-J model |
| 16 | **Yancheng Wang** | IOP, CAS | Quantum Spin Liquid with Even Ising Gauge Field Structure on Kagome Lattice |
| 17 | **Hanqing Wu** | California State U | Randomness induced spin-liquid-like phase in the spin-1/2 J1 - J2 triangular Heisenberg model |
| 18 | **Yining Xu** | Sun Yat-sen U | Spin glass in the bond-diluted J1–J2 Ising model on the square lattice |

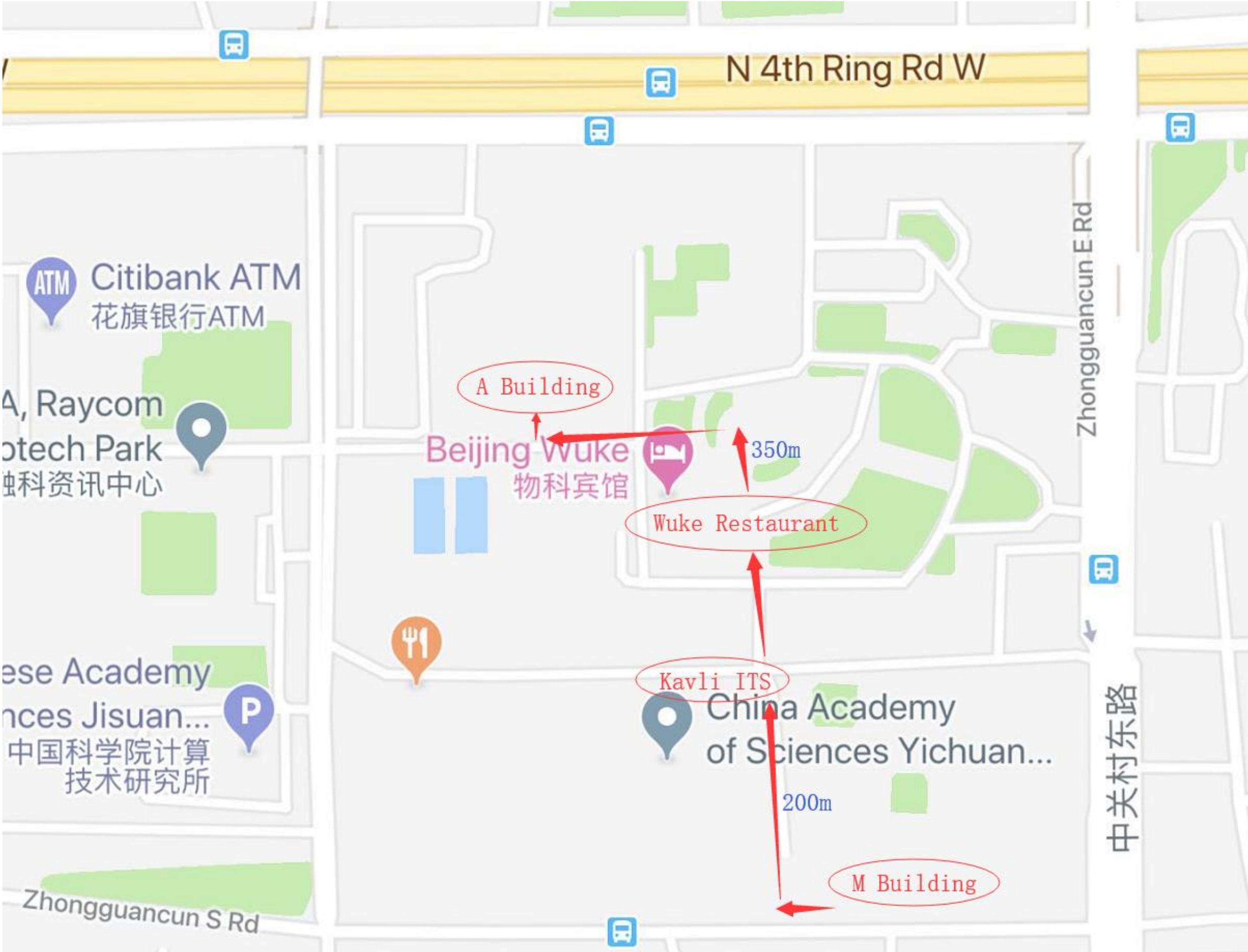
| | | | |
|---|---|---|---|
| 19 | **Xuping Yao** | Fudan | Pr2Ir2O7: when Luttinger semimetal meets Melko-Hertog-Gingras spin ice state |
| 20 | **Jianhao Zhang** | Tsinghua | Phenomenological Theory for Superconducting and Pseudogap Phases of High-T_Cuprates |
| 21 | **Zhaofeng Zhang** | Fudan | Muon Spin Relaxation/Rotation Study on Quantum Spin Liquid Candidate $YbMgGaO_4$ |
| 22 | **Chengkang Zhou** | Sun Yat-sen U | XXZ-Ising model on the triangular kagome lattice with spin 1 on the decorated trimers |

# Maps & Notes

Hotels to conference venue (IOP-M Building)



Surroundings



## Notes

### Wi-Fi Connection

**In the campus (IoP & KITS)**
Most areas of the campus are covered by eduroam.

**In M-Building Rm. 236(conference venue)**
SSID: WX-IOP
Password: iopcas1928

**In A-Building (guest offices)**
SSID: iop-guest
If you need it, please find the staff at the registration desk to get authorized.

### Offices

We arranged guest offices for speakers, please check your room No. when you register.

### Meals

Conference lunch will be at Wuke Restaurant.

### Contact

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