Frontiers in Condensed Matter Physics

Abstract Booklet

December 9-12, 2014

Korea Institute for Advanced Study, Seoul, Korea

KIAS KOREA INSTITUTE FOR ADVANCED STUDY

Abstract Booklet for

Frontiers in Condensed Matter Physics

Overseas Speakers

Andrey Chubukov (TPI, University of Minnesota)

Xi Dai (Institute of Physics, Chinese Academy of Sciences)

Akira Furusaki (RIKEN)

Masatoshi Imada (University of Tokyo)

Joel Moore (UC Berkeley)

Yukitoshi Motome (University of Tokyo)

Takashi Oka (University of Tokyo)

Masaki Oshikawa (ISSP, University of Tokyo)

Ying Ran (Boston College)

Jeorg Schmalian (Karlsruhe Institute of Technology)

Nic Shannon (Okinawa Institute of Science and Technology)

Oleg Tchernyshyov (Johns Hopkins University)

Fa Wang (Peking University)

Bohm-Jung Yang (RIKEN)

Hong Yao (Institute for Advanced Study, Tsinghua University)

Local Speakers

Suk-Bum Chung (Institute of Basic Science, Seoul National University)

Hosub Jin (Institute of Basic Science, Seoul National University)

Hongki Min (Seoul National University)

Kwon Park (KIAS)

Organizers

Yong-Baek Kim (KIAS, University of Toronto)

Kwon Park (KIAS)

Workshop on Frontiers in Condensed Matter Physics

KIAS, Seoul

9-12 December 2014

The workshop aims to provide a venue to discuss recent developments in diverse areas of condensed matter physics, including topological phases of matter, superconductivity, quantum criticality, and non-Fermi liquid physics.

Program

	12/9 (Tue)	12/10 (Wed)	12/11 (Thu)	12/12 (Fri)
09:00-09:30	Morning Coffee / Tea Time 09:20 Welcoming Speech*			
09:30-10:30	Chubukov	Imada	Moore	Oshikawa
10:30-11:00	Break			
11:00-12:00	Schmalian	Tchernyshov	Furusaki	Wang
12:00-14:00	Lunch			
14:00-15:00	Motome	Shannon	Ran	Dai
15:00-16:00	Yang	Park	Yao	Oka
16:00-16:30	Break	Excursion	Break	
16:30-17:30	Jin		Chung	Min
18:30-			Banquet (Holiday Inn Seongbuk)	

Talk Schedule

December 9 (Tue)

Morning Session

09:20-09:30 Welcoming Speech*

09:30-10:30 Chubukov Charge order in the cuprates

10:30-11:00 **Break**

11:00-12:00 Schmalian Topological Superconductivity in Oxide Interfaces

*Professor JongHae Keum, President of KIAS

12:00-14:00 **Lunch**

Afternoon Session

14:00-15:00 Motome Vaporization of Kitaev Spin Liquids

15:00-16:00 Yang Quantum criticality of topological phase transitions in 3D interacting electronic systems

16:00-16:30 **Break**

16:30-17:30 Jin Spin-orbital entangled molecular states in 4d and 5d lacunar spinel compounds

December 10 (Wed)

Morning Session

09:30-10:30 Imada Superconducting mechanisms of iron-based and cuprate superconductors

10:30-11:00 **Break**

11:00-12:00 Tchernyshov Gauge field, Majorana modes, and projective symmetry in the Kitaev honeycomb model

12:00-14:00 **Lunch**

Afternoon Session

14:00-15:00 Shannon Quantum Spin Ice

15:00-16:00 Park Enigmatic 5/2 State: Bilayer Mapping and Possibility of Anisotropic Pairing

Excursion (Insa-dong area; details are to be confirmed)

16:00-

December 11 (Thu)

Morning Session

09:30-10:30	Moore	Dynamical effects from topology in insulators and metals
10:30-11:00	**Break**	
11:00-12:00	Furusaki	Classification of topological phases of free fermions and its applications

12:00-14:00 **Lunch**

Afternoon Session

14:00-15:00	Ran	Chiral spin density wave, spin-charge-Chern liquid and d+id superconductivity in 1/4-doped correlated electronic systems on the honeycomb lattice
15:00-16:00	Yao	Emergent space-time supersymmetry in 3+1D Weyl and 2+1D Dirac semimetals
16:00-16:30	**Break**	
16:30-17:30	Chung	Majorana fermion from weak topological superconductivity: application to SrTiO3 and KTaO3

Banquet (Location: 2F, Holiday Inn Seongbuk)**

18:30-

**Bus leaves at 18:10 from the main gate of KAIST.

December 12 (Fri)

Morning Session

09:30-10:30	Oshikawa	Orbital Angular Momentum and Spectral Flow in Two Dimensional Chiral Superfluids
10:30-11:00	**Break**	
11:00-12:00	Wang	Schwinger boson spin liquid states on square lattice: projective symmetry group study
12:00-14:00	**Lunch**	

Afternoon Session

14:00-15:00	Dai	The Weyl semimetal phases generated by invasion symmetry breaking
15:00-16:00	Oka	Strong Field Physics in Condensed Matter: From Floquet Topological Insulator to the Zener-Schwinger Effect
16:00-16:30	**Break**	
16:30-17:30	Min	Interplay between chiral electronic structure and interactions in multilayer graphene

Charge order in the cuprates

Andrey V. Chubukov[1]

[1]*University of Minnesota, United States*

I analyze charge order in hole-doped cuprates. I argue that magnetically-mediated interaction, which is known to give rise to d-wave superconductivity, also gives rise to charge-density-wave instabilities with momenta Q_x =(Q,0) and Q_y =(0,Q), as seen in the experiments. I show that the emerging charge order with Q_x/Q_y is of stripe type and that a stripe charge order parameter by itself has two components: one is incommensurate density variation, another is incommensurate current. Both components are non-zero in the CDW-ordered state, with the relative phase +- \pi/2. Such an order breaks time reversal symmetry. I further show that, before a true incommensurate CDW order sets in, the system develops a pre-emptive composite order which breaks lattice rotational symmetry and time-reversal symmetry but preserves a translational U(1) symmetry. I discuss the interplay between our CDW order and superconductivity and the phase diagram of underdoped cuprates.

NOTES:

Vaporization of Kitaev Spin Liquids

Yukitoshi Motome[1], Joji, Nasu[2], and Masafumi Udagawa[1]

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

[2]*Department of Physics, Tokyo Institute of Technology, Japan*

The quantum spin liquid (QSL) is a new state of matter in magnets. This is a spin analogue of liquid helium that does not solidify down to the lowest temperature due to strong quantum fluctuations. Recently, several candidates for the QSL were discovered in quasi two-dimensional (2D) and three-dimensional (3D) compounds. In these compounds, the QSL is usually identified by the absence of thermodynamic anomalies down to the lowest temperature. Namely, it is implicitly supposed that a spin gas, corresponding to the high-temperature paramagnet, is adiabatically connected with the QSL. This common belief lends itself to the fact that liquid and gas are adiabatically connected with each other in conventional fluids.

In this study, we address the fundamental question on the thermodynamics of QSL: how does it develop as increasing temperature, or how is it distinguished from the paramagnet? We investigate the finite-temperature properties of 2D and 3D variants of the Kitaev model. The models are exactly soluble at zero temperature, and shown to be both gapless and gapped QSLs. Using a new quantum Monte Carlo technique on the basis of Majorana fermion representation, we clarify that the 3D system exhibits a phase transition at a nonzero temperature between QSL and paramagnet. On the other hand, there is no singularity in 2D. We show that the transition is characterized by topological nature of the loop structure in the excited states. Our results unveil that the "vaporization" of the QSL is quantitatively different from the conventional liquid-gas transition.

References

[1] J. Nasu, T. Kaji, K. Matsuura, M. Udagawa, and Y. Motome, Phys. Rev. B 89, 115125 (2014).

[2] J. Nasu, M. Udagawa, and Y. Motome, Phys. Rev. Lett. 113, 197205 (2014).

[3] J. Nasu, M. Udagawa, and Y. Motome, preprint (arXiv:1409.4865).

NOTES:

Quantum criticality of topological phase transitions in 3D interacting electronic systems

Bohm-Jung Yang[1]

[1] *RIKEN Center for Emergent Matter Science, Japan*

Topological phase transitions in condensed matters accompany emerging singularities of the electronic wave function, often manifested by gap-closing points in the momentum space. In conventional topological insulators in three dimensions (3D), the low energy theory near the gap-closing point can be described by relativistic Dirac fermions coupled to the long range Coulomb interaction, hence the quantum critical point of topological phase transitions provides a promising platform to test the novel predictions of quantum electrodynamics. Here we show that a new class of quantum critical phenomena emanates in topological materials breaking either the inversion symmetry or the time-reversal symmetry. At the quantum critical point, the theory is described by the emerging low energy fermions, dubbed the anisotropic Weyl fermions, which show both the relativistic and Newtonian dynamics simultaneously. The interplay between the anisotropic dispersion and the Coulomb interaction brings about a new screening phenomenon distinct from the conventional Thomas-Fermi screening in metals and logarithmic screening in Dirac fermions.

NOTES:

Spin-orbital entangled molecular states in 4*d* and 5*d* lacunar spinel compounds

Hosub Jin,[1,2]

[1] *Center for Correlated Electron Systems, Institute for Basic Science, Seoul , Korea*

[2] *Department of Physics and Astronomy, Seoul National University, Seoul, Korea*

The discovery of the effective-total-angular-momentum j_{eff} state in the layered 5*d* transition metal oxide Sr_2IrO_4 has provided a new viewpoint in understanding the electronic and magnetic properties of the system containing large spin-orbit coupling [1]. The spin-orbital entangled nature of the j_{eff} state can host various exotic phases with the help of electron correlations [2]. In this talk, we suggest that a series of 4*d* and 5*d* transition metal compounds, AM_4X_8, host the molecular form of the j_{eff} state in their low energy electronic structures. Wide range of electron correlations are accessible by means of tuning the bandwidth under the external and/or chemical pressure, enabling us to investigate the interesting cooperation between SOC and electron correlations. On the way to search the possibility of the various emergent phases with respect to the competing electron correlation strength, we briefly elucidate the topological insulating phase and the complicated spin model in the weak and strong coupling limit, respectively.

References

[1]B. J. Kim *et al.*, Phys. Rev. Lett. **101**, 076402 (2008).

[2]For a review, see W. Witczak-Krempa, G. Chen, Y. B. Kim, and L. Balents, Annu. Rev. Condens. Matter Phys. **5**, 57 (2014).

NOTES:

Superconducting mechanisms of iron-based and cuprate superconductors

Masatoshi Imada[1]

[1]*The University of Tokyo, Japan*

Two families of high temperature superconductors whose critical temperatures are higher than 50K are known. One is the copper oxides and the other is the iron-based superconductors. Here we first present an overview of the ab initio numerical method developed for strongly correlated electron systems. This multi-scale ab initio scheme for the correlated electrons is applied to an electron-doped iron-based superconductor LaFeAsO. The superconductivity is reproduced in the variational Monte Carlo calculations in accordance with the experiments[1]. Then the mechanism of the superconductivity is identified as enhanced uniform density fluctuations by one-to-one correspondence with the instability toward inhomogeneity driven by first-order antiferromagnetic (AF) and nematic transitions. The mechanism is analyzed in terms of the underlying orbital selective Mottness. Despite many differences, certain common features with the copper oxides are found[2]. The emergence of the superconductivity in the copper oxides is separately analyzed by the cluster dynamical mean-field calculations[3]. One-to-one correspondence of the gap function and the Green's function between the model for the cuprates and a simple two-component fermion model support the existence of hidden fermions emerging from the strong electron correlation and giving birth to the strongly bound Cooper pairs. The hidden fermions survive even above Tc and generate the strange-metal pseudogap phase. The work on the iron based superconductors was done in collaboration with Takahiro Misawa and the studies on the cuprates were achieved in collaboration with Shiro Sakai and Marcello Civelli.

References

[1] T. Misawa and M. Imada: Phys. Rev. Lett. 108, 177007 (2012), arXiv:1409.6536, Nat. Commun. in press.
[2] T. Misawa and M. Imada: Phys. Rev. B 90, 115137 (2014).
[3] S. Shiro, M. Civelli and M. Imada: arXiv:1411.4365

NOTES:

Gauge field, Majorana modes, and projective symmetry in the Kitaev honeycomb model

Oleg Tchernyshyov[1]

[1] *Johns Hopkins University, United States*

The Kitaev honeycomb spin model admits an exact solution in terms of Majorana fermions living in the background of a static Z_2 gauge field. Its ground state is a featureless spin liquid whose nontrivial properties can be revealed by introducing lattice defects. Willans et al. have shown that even simple vacancy defects induce very nontrivial response: free magnetic moments with only one spin component [1]. We have found that topological lattice defects–dislocations–generate even more exotic response: unpaired Majorana modes [2]. A physical qubit consists of two such Majorana modes connected by a string of the Z_2 gauge field. This gauge field, neglected in most treatments of the Kitaev model, plays a major role in shaping up symmetries of the system. The multiplicity of Majorana fermion excitations can only be understood in the framework of Wen's projective symmetry group, which combines physical symmetries with gauge transformations [3].

References

[1] A. J. Willans, J. T. Chalker, and R. Moessner, Phys. Rev. B **84**, 115146 (2011).

[2] O. Petrova, P. Mellado, and O. Tchernyshyov, Phys. Rev. B **90**, 134404 (2014).

[3] P. Mellado, O. Petrova, and O. Tchernyshyov, arXiv:1409.7460.

NOTES:

Quantum Spin Ice

Nic SHANNON[1], Owen BENTON[1], Paul McClarty[2], Olga SIKORA[3],
Peter FULDE[4], Roderich MOESSNER[4], Karlo PENC[5] and Frank POLLMANN[4]

[1]*Okinawa Institute of Science and Technology Graduate University, Japan.*
[2]*ISIS, Rutherford Appleton Laboratory, Harwell, UK.*
[3]*Taiwan National University, Department of Physics, Tapei, Taiwan.*
[4]*Max Planck Institute for the Physics of Complex Systems, Dresden, Germany.*
[5]*Research Institute for Solid State Physics and Optics, Budapest, Hungary.*

Spin ice, with its magnetic monopole excitations, is perhaps the outstanding example a classical spin liquid. However the role of quantum effects in spin ice materials is relatively little understood, and the nature of their equilibrium ground state remains an open question. This question gains fresh urgency from recent experiments which suggest that the spin ice $Dy_2Ti_2O_7$ may undergo a phase transition at low temperature [1], and from "quantum spin-ice" materials like $Yb_2Ti_2O_7$, where quantum effects are expected to play a much larger role [2].

Here we explore how quantum tunnelling between different ice configurations changes the ground state phase diagram of a spin ice [3]. We consider a model directly motivated by $Dy_2Ti_2O_7$, in which long-range dipolar interactions, and competing second-neighbour exchange, are also taken into account. We identify the possible ordered ground states relevant to $Dy_2Ti_2O_7$, and establish that, a for realistic choice of parameters, only a small amount of quantum tunnelling is needed to convert these ordered states into a quantum spin liquid with photon-like excitations [4-8].

References

[1] D. Pomaranski *et al.*, Nature Phys. **9**, 353 (2013).
[2] K. Ross *et al.*, Phys. Rev. X **1**, 021002 (2012).
[3] P. McClarty *et al.*, arXiv:1410.0451
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[6] N. Shannon *et al.*, Phys. Rev. Lett. **108**, 067204 (2012).
[7] O. Benton *et al*., Phys. Rev. B **86**, 075154 (2012).
[8] Y. Kato *et al*., arXiv:1411.1918

NOTES:

Enigmatic 5/2 State: Bilayer Mapping and Possibility of Anisotropic Pairing

Kwon Park[1]

[1]*Korea Institute for Advanced Study, Korea*

One of the most dominant candidates for the paired quantum Hall (QH) state at filling factor 5/2 is the Moore-Read (MR) Pfaffian state. A salient problem, however, is that it does not occur exactly at the Coulomb interaction, but rather at modified interactions, which favor particle-hole (PH) symmetry breaking. In an effort to find a better state, in this work, we investigate the possible connection between the paired QH state and the antisymmetrized bilayer ground state, which is inspired by the intriguing identity that the MR Pfaffian state is entirely equivalent to the antisymmetrized bilayer QH state called the Halperin (331) state, which is valid at interlayer distance roughly equal to the magnetic length. Specifically, by using exact diagonalization in the torus geometry, we show that the exact 5/2 state at a given Haldane pseudopotential variation is intimately connected with the antisymmetrized bilayer ground state at a corresponding interlayer distance via one-to-one mapping, which we call the bilayer mapping. One of the most important discoveries in this work is that the paired QH state occurring at the Coulomb interaction is mapped onto the antisymmetrized bilayer ground state in the limit of large interlayer distance, which is equivalent to the antisymmetrized product state of two composite fermion (CF) seas at quarter filling, not the MR Pfaffian state. While maintaining high overlap with the paired QH state, the antisymmetrized bilayer ground state at large interlayer distance exhibits an abrupt change under the influence of small anisotropy. This suggests that the paired QH state occurring at the Coulomb interaction might be susceptible to anisotropic instability, opening up the possibility of anisotropic p_x or p_y-wave pairing instead of $p_x \pm ip_y$-wave pairing in the MR Pfaffian/anti-Pfaffian state.

NOTES:

Classification of topological phases of free fermions and its applications

Akira Furusaki[1]

[1]*RIKEN, Japan*

I will first review classification of topological insulators and topological superconductors and explain how the periodic table can be obtained by classifying Dirac mass terms using Clifford algebras. This is a simplified version of Kitaev's derivation. I will then discuss some applications of this approach, e.g., to Weyl/Dirac semimetals and disordered systems.

NOTES:

Chiral spin density wave, spin-charge-Chern liquid and d+id superconductivity in 1/4-doped correlated electronic systems on the honeycomb lattice

Ying Ran[1]

[1]*Boston College, United States*

Recently two interesting candidate quantum phases --- the chiral spin density wave state featuring anomalous quantum Hall effect and the d+id superconductor --- were proposed for the Hubbard model on the honeycomb lattice at 1/4 doping. Using a combination of exact diagonalization, density matrix renormalization group, the variational Monte Carlo method and quantum field theories, we study the quantum phase diagrams of both the Hubbard model and t-J model on the honeycomb lattice at 1/4-doping. The main advantage of our approach is the use of symmetry quantum numbers of ground state wavefunctions on finite size systems to sharply distinguish different quantum phases. Our results show that for $1\lesssim U/t< 40$ in the Hubbard model and for $0.1< J/t<0.80(2)$ in the t-J model, the quantum ground state is either a chiral spin density wave state or a spin-charge-Chern liquid, but not a d+id superconductor. However, in the t-J model, upon increasing J the system goes through a first-order phase transition at $J/t=0.80(2)$ into the d+id superconductor. Here the spin-charge-Chern liquid state is a new type of topologically ordered quantum phase with Abelian anyons and fractionalized excitations. Experimental signatures of these quantum phases, such as tunneling conductance, are calculated. These results are discussed in the context of 1/4-doped graphene systems and other correlated electronic materials on the honeycomb lattice.

NOTES:

Emergent space-time supersymmetry in 3+1D Weyl and 2+1D Dirac semimetals

Hong Yao[1]

[1]*IAS, Tsinghua University, China*

Supersymmetry (SUSY) interchanges bosons and fermions but no direct evidences of it have been revealed in nature yet. In this paper, we observe that fluctuating pair density waves (PDW) consist of two complex order parameters which can be superpartners of the unavoidably-doubled Weyl fermions in 3+1D lattice models. Using renormalization group, we theoretically show that SUSY emerges at PDW transitions in 3+1D Weyl semimetals (2+1D Dirac semimetals). We construct explicit fermionic lattice models featuring 3+1D Weyl fermions (2+1D Dirac fermions) and showthat PDW is the leading instability as short-range interactions exceed a critical value and that the N = 2 SUSY emerges at the continuous PDW transitions. We further discuss possible routes to realize these lattice models and experimental signatures of emergent SUSY at the PDW criticality.

NOTES:

Majorana fermion from weak topological superconductivity: application to SrTiO3 and KTaO3

Suk Bum Chung[1]

[1]*Institute for Basic Science: Center for Correlated Materials, Seoul National University, Korea*

Much of the current experimental efforts for detecting Majorana zero modes centered on probing the boundary of quantum wires with strong spin-orbit coupling. It is possible to realize the same type of Majorana zero mode at crystalline dislocation in the 2D superconductor, which has non-zero weak topological indices. Unlike at an Abrikosov vortex, at such a dislocation, there will not be midgap states other than the Majorana zero mode that can complicate the experimental detection. We will show that, using the anisotropic dispersion of the Ti / Ta t2g orbitals, such a weak topological superconductivity can be realized when the surface 2DEG of SrTiO3 or KTaO3 becomes superconducting.

NOTES:

Orbital Angular Momentum and Spectral Flow in Two Dimensional Chiral Superfluids

Masaki Oshikawa[1]

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

The total orbital angular momentum in a chiral superfluid has posed a paradox for several decades [1]. For a *p*+*ip*-wave superfluid consists of *N* fermions, on one hand, the total orbital angular momentum seems to be *N*/2 because there would be *N*/2 Cooper pairs, each of which has the orbital angular momentum 1. On the other hand, starting from the normal Fermi liquid with zero angular momentum, the angular momentum appears to be strongly suppressed from *N*/2, since only the fermions near the Fermi surface would be affected by the pairing amplitude. To resolve the issue, we study the well-defined problem of the Bogoliubov-de Gennes Hamiltonian for chiral superfluids in a two-dimensional circular well [2]. Through the conserved charge introduced by Volovik [3], the total orbital angular momentum of the system is determined by spectral flows. In a large enough system, we find that the total orbital angular momentum takes the full value *N*/2 in the chiral *p*+*ip*-wave superfluid. However, in the higher-order chiral superfluids (*d*+*id*, *f*+*if*, etc.) the total orbital angular momentum is strongly suppressed from the full value. The surprising difference is related to the structure of edge states.

References

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[2] Y. Tada, W. Nie, and M. O., arXiv:1409.7459 (to be published in Phys. Rev. Lett.)

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NOTES:

Schwinger boson spin liquid states on square lattice: projective symmetry group study

Fa Wang[1]

[1]*Peking University, China*

We will report our results on possible spin liquids on square lattice that respect all lattice symmetries and time-reversal symmetry within the framework of Schwinger boson (mean-field) theory. Such spin liquids have spin gap and emergent Z_2 gauge field excitations. We classify them by the projective symmetry group method, and find six spin liquid states that are potentially relevant to the J_1-J_2 Heisenberg model. The properties of these states are studied under mean-field approximation and by projected wave functions on small lattices. Interestingly we find a spin liquid state that can possibly go through continuous phase transitions to either Neel magnetic order or magnetic order of wavevector at Brillouin zone edge center. We propose that this state may be realized in J_1-J_2 Heisenberg model with ring exchange.

NOTES:

Strong Field Physics in Condensed Matter: From Floquet Topological Insulator to the Zener-Schwinger Effect

Takashi Oka[1]

[1]*University of Tokyo, Japan*

The effect of strong laser on many-electron systems is becoming a hot topic[1,2,3]. Recently, a theoretical proposal was made in two dimensional Dirac systems where an application of circularly polarized light was shown to turn the system into a quantum Hall state (Fig.1) with a non-trivial photo-induced Chern number and an emergence of edge channels[1,2]. One can see this as a dynamical realization of the Haldane model of a quantum Hall state without Landau levels[4]. This effect can be understood with the help of the Floquet theory of driven quantum systems, where the circularly polarized light plays the role similar to the "next nearest hopping with a nontrivial phase factor" in the Haldane model.

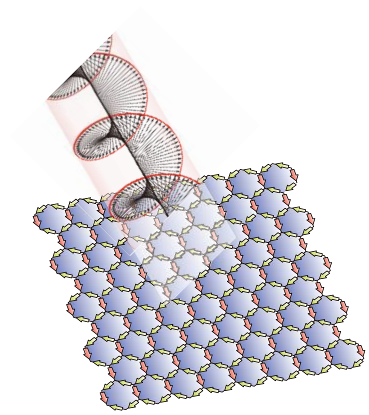

Fig.1: Graphene in circularly polarized light becomes a laser induced quantum Hall state.

In addition, I will discuss the theory and recent experiment of the Zener-Schwinger effect in strongly correlated insulators.

* This work has been done in collaboration with T. Mikami (Tokyo-U), K. Yasuda (Tokyo-U), N. Tsuji (Tokyo-U), H. Aoki (Tokyo-U), S. Takayoshi (NIMS), and M. Sato (Aoyama Gakuin).

References

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NOTES:

Interplay between chiral electronic structure and interactions in multilayer graphene

Hongki Min[1]

[1]*Seoul National University, Korea*

Recently, multilayer graphene has attracted considerable attention because of exotic chiral features in its electronic structure, and because of the possibility for future electronic device applications. A fundamental issue in multilayer graphene is the interplay between the chiral electronic structure and interactions, such as electron-electron and electron-impurity interactions. In this talk, we first discuss the electronic structure of multilayer graphene, showing that the energy band structure strongly depends on its stacking sequence and that the extra sublattice/layer degrees of freedom, called pseudospin, play an important role. Next, we discuss the implications of the chiral electronic structure for the interaction induced phenomena.

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