1 Aoki Group

Subject: Theoretical condensed-matter physics

Our main interests are many-body and topological effects in electron and cold-atom systems, i.e., **superconductivity, magnetism and topological phenomena**, for which we envisage **materials design** and novel **non-equilibrium** phenomena should be realised. Studies around the 2018 academic year include:

- **Superconductivity**
  - — Electron correlation and High-Tc superconductivity
    - Dynamical vertex approximation (DΓA)[1], see Fig.1.1.1
    - DMFT with a slave-particle impurity solver [2]
    - Superconducting mechanism for a new-type cuprate $Ba_2CuO_{3+\delta}$ [3]
    - Nickelate superconductor[4]
  - — Design of flat bands and flat-band superconductivity[5, 6],
- **Topological systems**
  - — Chiral symmetry in graphene-related systems[7]
  - — Valley and spin polarisation in bilayer graphene and transition-metal dichalcogenides[8, 9]
- **Non-equilibrium and non-linear phenomena**
  - — Relaxation dynamics in doped repulsive Hubbard model[10],
  - — "Imprinting" of topological states by spatially-periodic circularly-polarised light[11]
  - — Higgs modes in high-Tc, d-wave superconductors[12]

[1] Motoharu Kitatani, Thomas Schäfer, Hideo Aoki and Karsten Held: Why T_c is so low in high-T_c cuprates: importance of the dynamical vertex structure, *Phys. Rev. B* **99**, 041115(R) (2019).

[2] Sharareh Sayyad, Naoto Tsuji, Massimo Capone and Hideo Aoki: SO(4) FLEX+DMFT formalism with SU(2)⊗SU(2)-symmetric impurity solver for superconductivity in the repulsive Hubbard model, arXiv:1903.05800.

[3] K. Yamazaki, M. Ochi, D. Ogura, K. Kuroki, H. Eisaki, S. Uchida and H. Aoki: Superconducting mechanism for a new-type cuprate $Ba_2CuO_{3+\delta}$ based on a multiorbital Lieb lattice model, arXiv:2003.04015.

[4] Hirofumi Sakakibara, Hidetomo Usui, Katsuhiro Suzuki, Takao Kotani, Hideo Aoki, and Kazuhiko Kuroki: Model construction and a possibility of cuprate-like pairing in a new d^9 nickelate superconductor (Nd,Sr)NiO_2, arXiv:1909.00060.

[5] Sharareh Sayyad, Edwin W. Huang, Motoharu Kitatani, Mohammad-Sadegh Vaezi, Zohar Nussinov, Abolhassan Vaezi and Hideo Aoki: Pairing and non-Fermi liquid behavior in partially flat-band systems, *Phys. Rev. B* **101**, 014501 (2020).

[6] Hideo Aoki: Theoretical possibilities for flat-band superconductivity, *Journal of Superconductivity and Novel Magnetism*, DOI: 10.1007/s10948-020-05474-6 (arXiv:1912.04469).

[7] Tohru Kawarabayashi, Hideo Aoki and Yasuhiro Hatsugai: Topologically protected doubling of tilted Dirac fermions in two dimensions, *Proc. 34th Int. Conf. on Physics of Semiconductors*, Montpellier, France, July 2018 [*Phys. Status Solidi* B, 2019, 1800524].

[8] P. A. Maksym and H. Aoki: Complete spin and valley polarization by total external reflection from potential barriers in bilayer graphene and monolayer transition metal dichalcogenide, arXiv:1911.03077.

[9] P.A. Maksym and H. Aoki: Fast split operator method for computation of time-dependent qantum states of bilayer graphene in a magnetic field, *Physica E* **112**, 66 (2019).

[10] Sharareh Sayyad, Naoto Tsuji, Abolhassan Vaezi, Massimo Capone, Martin Eckstein and Hideo Aoki: Momentum-dependent relaxation dynamics of the doped repulsive Hubbard model, *Phys. Rev. B* **99**, 165132 (2019).

[11] Hwanmun Kim, Hossein Dehghani, Hideo Aoki, Ivar Martin, and Mohammad Hafezi: Optical imprinting of superlattices in 2D materials, arXiv:1912.13059.

[12] Kota Katsumi, Naoto Tsuji, Yuki I. Hamada, Ryusuke Matsunaga, John Schneeloch, Ruidan D. Zhong, Genda D. Gu, Hideo Aoki, Yann Gallais, Ryo Shimano: Higgs mode in the d-wave superconductor $Bi_2Sr_2CaCu_2O_{8+x}$ driven by an intense terahertz pulse, *Phys. Rev. Lett.* **120**, 117001 (2018) (Editor's suggestion).

Gallery

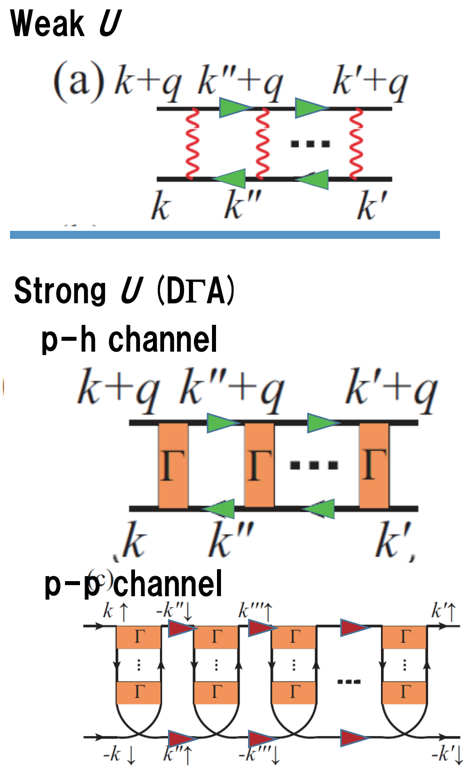

図 1.1.1: Top: Antiferromagnetic spin fluctuations for weak interaction U (red wiggled lines) in terms of particle-hole ladder diagrams (solid line: Green's function). Middle: DΓA diagrams describe similar spin fluctuations but now for strong correlation, with ladders (in the particle-hole channel; green arrows) of the vertex Γ which is non-perturbative and frequency-dependent. Bottom: DΓA further incorporates the diagrams in the particle-particle channel (red arrows).[1]

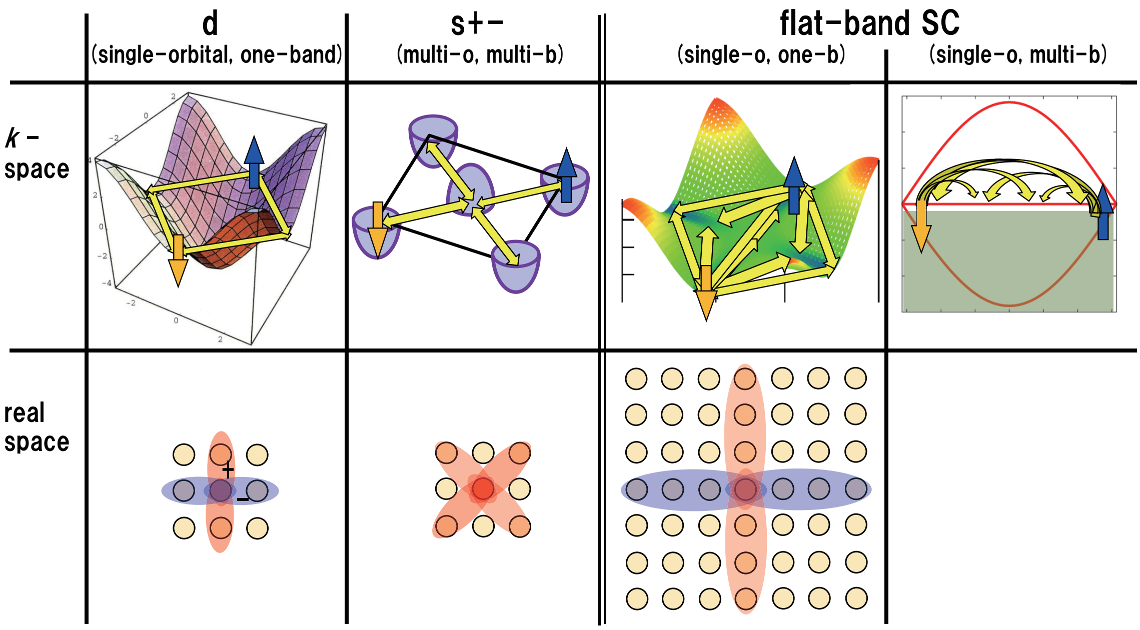

図 1.1.2: We schematically compare ordinary single-orbital, one-band case (here for a d-wave SC; leftmost column) and multi-orbital, multi-band case (here for $s_{\pm}$; second column from left), where the nesting vectors (yellow arrows) connecting the specific “hot spots” designate how pairs (blue and orange arrows) are scattered. These are contrasted with flat-band systems for single-orbital, one-band case (second from right) and single-orbital, multi-band case (rightmost), where yellow arrows again represent pair-scattering channels. The top row depicts k-space, while the bottom row displays pairs in real space. [5, 6]

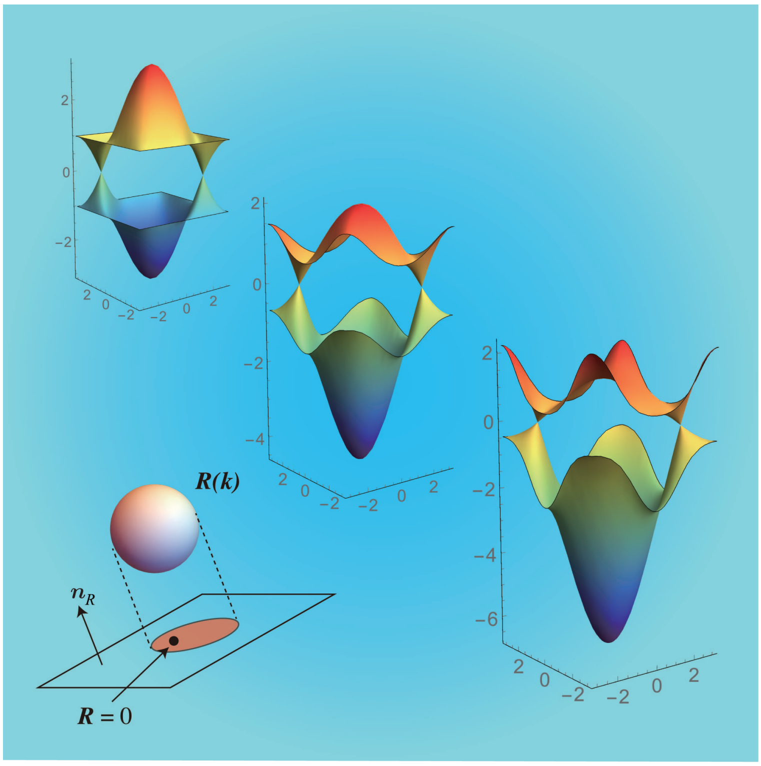

図 1.1.3: Energy dispersions are shown when the Hamitonian for the honeycomb lattice is algebraically deformed with a parameter q, which produces tilted Dirac cones.[7] The left bottom inset depicts how the surface $\mathbf{R}(\mathbf{k})$ with $\mathbf{k}$ traversing over the Brillouin behaves in general (a three-dimensional object), or for the Dirac-cone case (collapsed), which shows schematically why the Dirac cones always appear in pairs. Here $\mathbf{R}(\mathbf{k})$ is a parameter describing the Dirac Hamiltonian.

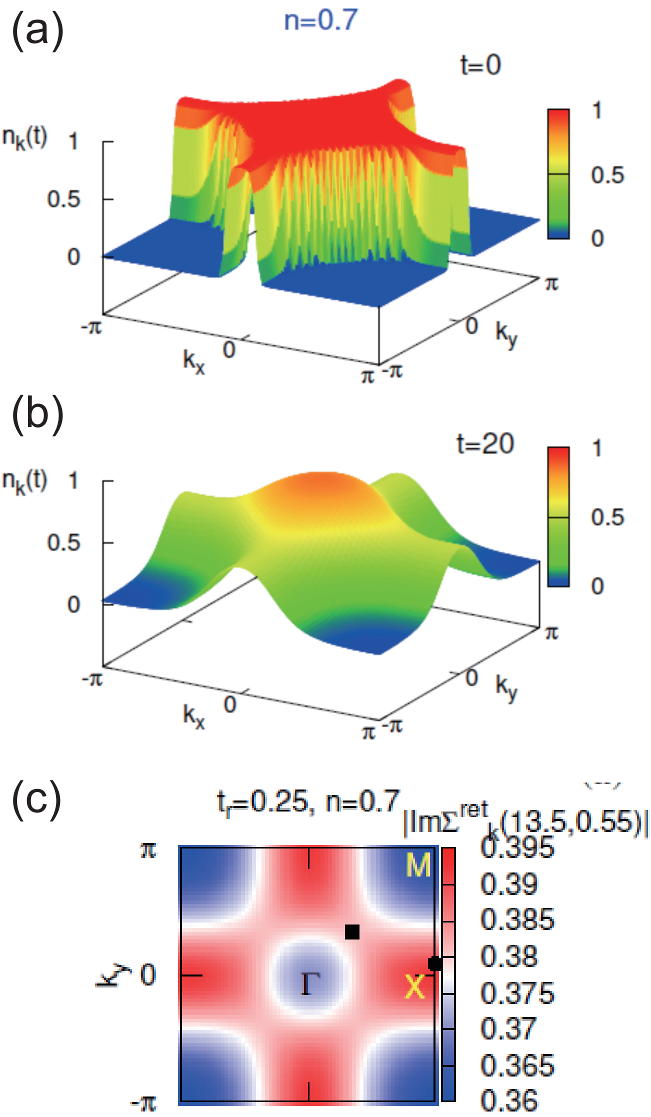

図 1.1.4: For a hole-doped filling $n = 0.7$ the momentum-dependent distribution fun ctions, $n_k(t)$, at initial $t = 0$ (a) and final $t = 20$ (b) are plotted for the repulsive interaction changed from zero to $U = 3$ in the Hubbard model. (c) Momentum dependence of the self-energy, $\mathrm{Im}|\Sigma_k(t)|$, after the ramp. [10]