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 2017 academic year include:

- **Superconductivity**
  - — Electron correlation and High-Tc superconductivity
    - Dynamical vertex approximation (DΓA)[1]
  - — Design of flat bands and flat-band superconductivity[2, 3]
  - — Tc dome and Pomeranchuk instability[4]
  - — Design of ladder compounds[5]
- **Topological systems**
  - — Quantum Hall effect and chiral symmetry in graphene[6]
  - — Designed ferromagnetic and topological organic material[7]
  - — Three-dimensional graphene[8, 9, 10]
  - — Electronic birefringence in bilayer graphene
- **Non-equilibrium and non-linear phenomena**
  - — Higgs modes in superconductors
    - Conventional, s-wave superconductors[11, 12, 13]
    - High-Tc, d-wave superconductors[14]
  - — Collective excitations in two-band superconductors[15]
  - — Superconductivity in non-equilibrium[16]
  - — Floquet topological phase transitions[17, 18]

[1] Motoharu Kitatani, Thomas Schäfer, Hideo Aoki and Karsten Held: Why $T_{\rm c}$ is so low in high-$T_{\rm c}$ cuprates: importance of the dynamical vertex structure, arXiv:1801.05991.

[2] Keita Kobayashi, Masahiko Okumura, Susumu Yamada, Masahiko Machida, and Hideo Aoki: Superconductivity in repulsively interacting fermions on a diamond chain — flat-band induced pairing, *Phys. Rev. B* **94**, 214501 (2016).

[3] Tatsuhiro Misumi and Hideo Aoki; A new class of flat-band models on tetragonal and hexagonal lattices: gapped vs crossing flat bands, *Phys. Rev. B* **96**, 155137 (2017) (Editor's suggestion).

[4] Motoharu Kitatani, Naoto Tsuji and Hideo Aoki: Interplay of Pomeranchuk instability and superconductivity in the two-dimensional repulsive Hubbard model, *Phys. Rev. B* **95**, 075109 (2017).

[5] Daisuke Ogura, Hideo Aoki and Kazuhiko Kuroki: Possible high-T_c superconductivity due to incipient narrow bands originating from hidden ladders in Ruddlesden-Popper compounds, *Phys. Rev. B* **96**, 184513 (2017).

[6] Tohru Kawarabayashi, Hideo Aoki and Yasuhiro Hatsugai: Lattice realization of the generalized chiral symmetry in two dimensions, *Phys. Rev. B* **94**, 235307 (2016).

[7] Masahiko G. Yamada, Tomohiro Soejima, Naoto Tsuji, Daisuke Hirai, Mircea Dinca and Hideo Aoki: First-principles design of a half-filled flat band of the Kagome lattice in two-dimensional metal-organic frameworks, *Phys. Rev. B* **94**, 081102(R) (2016).

[8] Mikito Koshino and Hideo Aoki: Dirac electrons on three-dimensional graphitic zeolites — a scalable mass gap, *Phys. Rev. B* **93**, 041412(R) (2016).

[9] Yoichi Tanabe, Yoshikazu Ito, Katsuaki Sugawara, Daisuke Hojo, Mikito Koshino,Takeshi Fujita, Tsutomu Aida, Xiandong Xu, Khuong Kim Huynh, Hidekazu Shimotani, Tadafumi Adschiri, Takashi Takahashi, Katsumi Tanigaki, Hideo Aoki, and Mingwei Chen: Electric properties of Dirac fermions captured into 3D nanoporous graphene networks, *Advanced Materials* **28**, 10304 (2016).

[10] Yoshikazu Ito, Yoichi Tanabe, Katsuaki Sugawara, Mikito Koshino, Takashi Takahashi, Katsumi Tanigaki, Hideo Aoki, and Mingwei Chen: Three-dimensional porous graphene networks expand graphene-based electronic device applications, *Phys. Chem. Chem. Phys.*, DOI: 10.1039/c7cp07667c.

[11] Y. Murakami, P. Werner, N. Tsuji and H. Aoki: Damping of the collective amplitude mode in superconductors with strong electron-phonon coupling, *Phys. Rev. B* **94**, 115126 (2016).

[12] Naoto Tsuji, Yuta Murakami and Hideo Aoki: Nonlinear light-Higgs coupling in superconductors beyond BCS: Effects of the retarded phonon-mediated interaction, *Phys. Rev. B* **94**, 224519 (2016).

[13] Ryusuke Matsunaga, Naoto Tsuji, Kazumasa Makise, Hirotaka Terai, Hideo Aoki, and Ryo Shimano: Polarization-resolved terahertz third-harmonic generation in a superconductor NbN: dominance of Higgs mode beyond the BCS approximation, *Phys. Rev. B* **96**, 020505(R) (2017).

[14] 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).

[15] Yuta Murotani, Naoto Tsuji and Hideo Aoki: Theory of light-induced resonances with collective Higgs and Leggett modes in multiband superconductors, *Phys. Rev. B* **95**, 104503 (2017).

[16] Sota Kitamura and Hideo Aoki: η-pairing superfluid in periodically-driven fermionic Hubbard model with strong attraction, *Phys. Rev. B* **94**, 174503 (2016).

[17] Takahiro Mikami, Sota Kitamura, Kenji Yasuda, Naoto Tsuji, Takashi Oka and Hideo Aoki: Brillouin-Wigner theory for high-frequency expansion in periodically driven systems — Application to Floquet topological insulators, *Phys. Rev. B* **93**, 144307 (2016).

[18] Sota Kitamura, Takashi Oka and Hideo Aoki: Probing and controlling spin chirality in Mott insulators by circularly polarized laser, *Phys. Rev. B* **96**, 014406 (2017).

Gallery

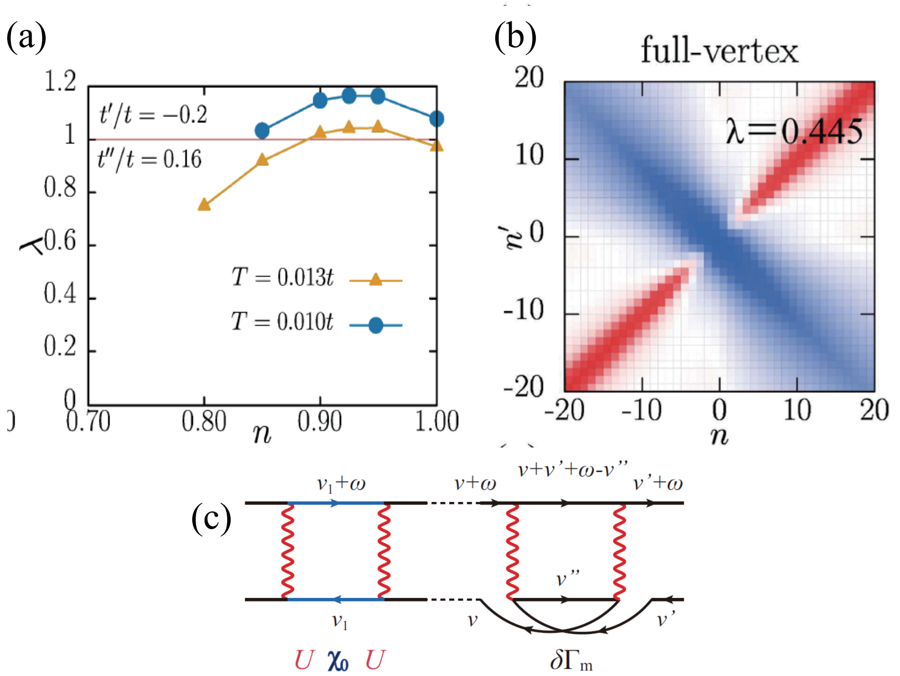

図 1.1.8: (a) Dynamical vertex approximation (DΓA) result for the eigenvalue λ (a measure of Tc, for the d-wave pairing in the present case) of the Eliashberg equation against the band filling n for the repulsive interaction $U = 6t$ at temperatures $T/t = 0.010, 0.013$ in the Hubbard model for a high-Tc cuprate. (b) The local vertex correction $\delta\Gamma_{\mathrm{m}}(\nu_n, \nu_{n'}, \omega = 0) \equiv \Gamma_{\mathrm{m}}(\nu_n, \nu_{n'}, \omega = 0) - (-U)$ is plotted against frequencies $\nu_n, \nu_{n'}$ (blue: positive; red: negative). (c) The magnetic verteces that appear in the Bethe-Salpeter equation. Left: a typical diagram as in RPA with U (red wavy line) as an irreducible building block, connected by χ_0 (two blue Green's functions with fermionic frequencies ν_1 and $\nu_1 + \omega$. Right: Local (here second-order) vertex corrections with a particle-particle bubble. They lead to a suppression of Tc. After Ref.[1].

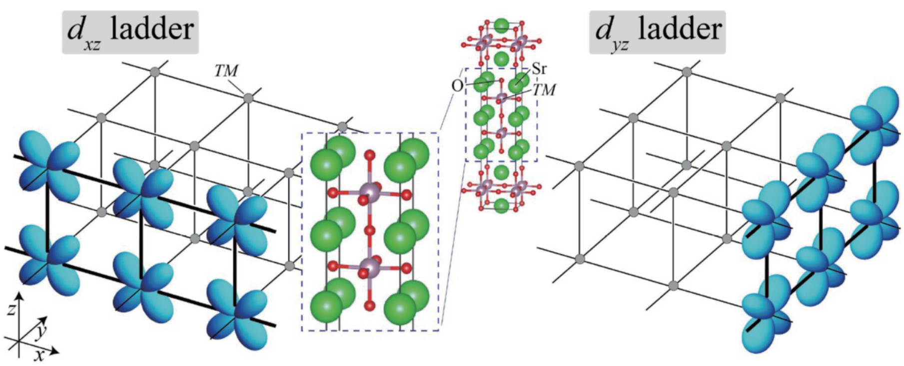

図 1.1.9: A Ruddlesden-Popper compound $Sr_3TM_2O_7$ (TM: transition metal) may seem to be a simple double layer (black lattice), but is a two-leg ladder in fact if we consider the d orbitals of TM, here d_{xz} (left panel) and d_{yz}(right). After Ref.[5].

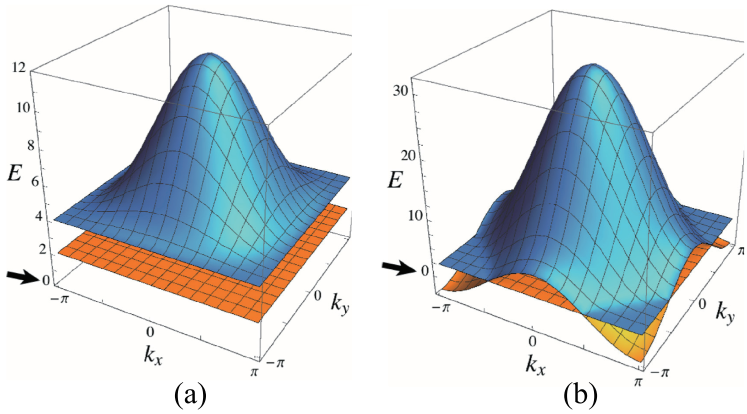

図 1.1.10: (a) A flat-band model in which we can control the energy position of the flat band. There, the flat band is in general different from zero (an arrow). (b) A newly constructed model in which the flat band pierces a dispersive one. After Ref.[3].

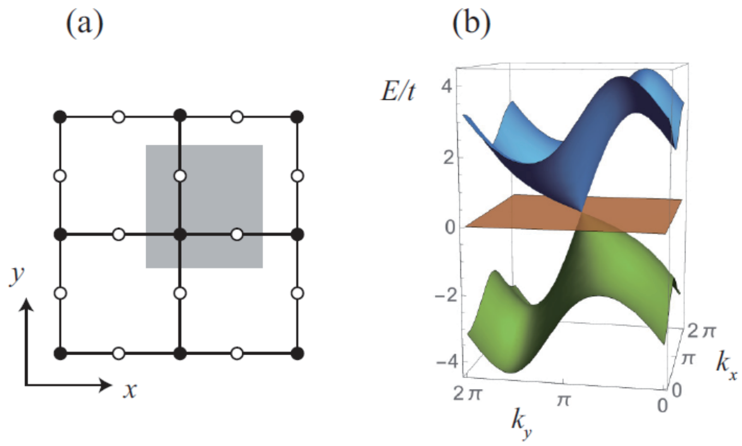

図 1.1.11: (a) A typical example of flat-band models (here Lieb lattice). (b) Band structure when we "deform" the model, in which we can see that the flat band pierces the Dirac point of a tilted Dirac cone. After Ref.[6].

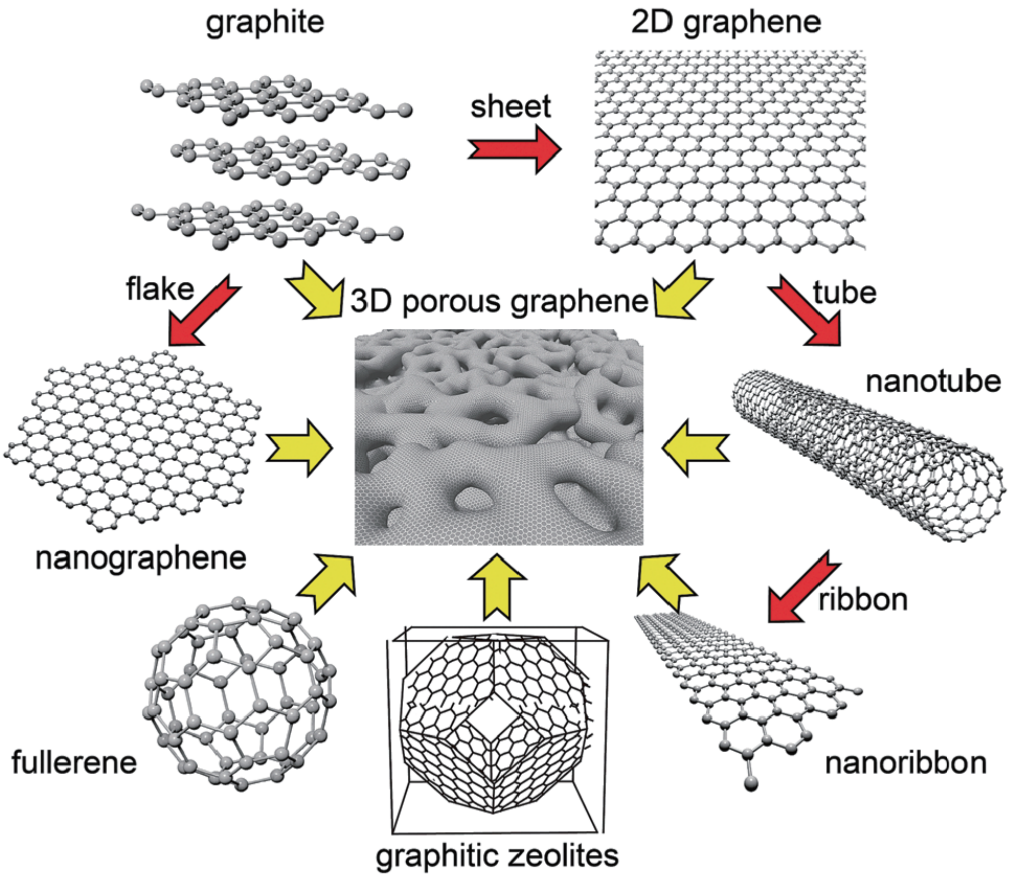

図 1.1.12: Various families of carbon structures. After Ref.[10].

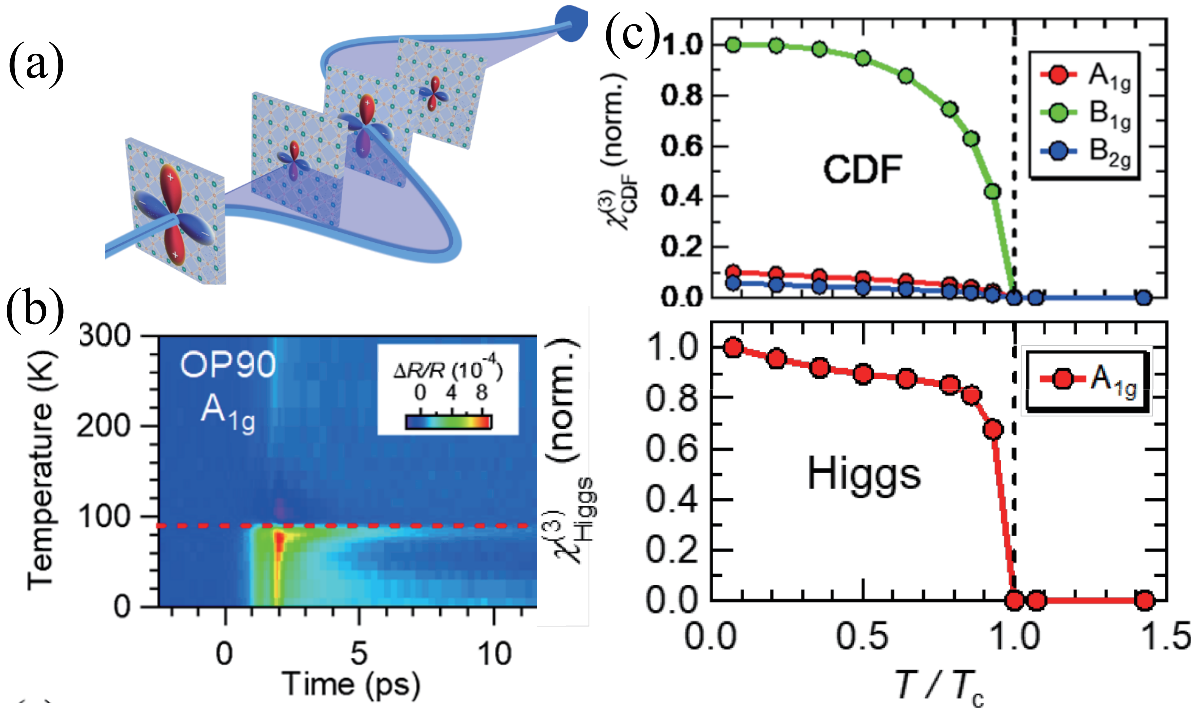

図 1.1.13: (a) An oscillating d-wave superconductivity order parameter when a high-Tc cuprate is illuminated by a THz laser pulse is schematically shown. (b) Experimental result for the change in the reflectivity (which corresponds to the third-order nonlinear optical response $\chi^{(3)}$) induced by the laser pulse is plotted for various temperatures, here for the A_{1g} component among various irreducible representations for the curate crystal. A horizontal dashed line indicates Tc. (c) Theoretical result for the third-order nonlinear optical response $\chi^{(3)}$ is plotted against temperature, here resolved into various irreducible representations for each of the charge-density fluctuations (CDF) contribution and the Higgs mode contribution. After Ref.[14].

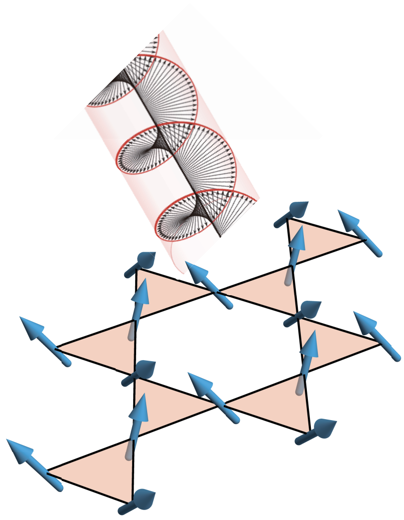

図 1.1.14: A chiral spin structure can be induced when a circularly-polarised light is illuminated to a strongly-correlated electron system. After Ref.[18].