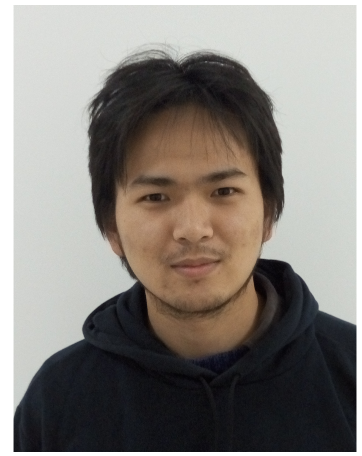
Some research topics of Gang Chen's group

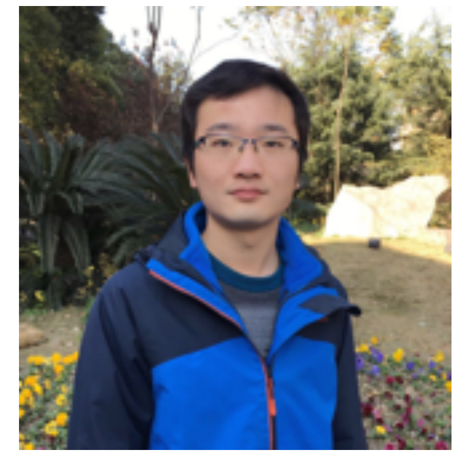
Gang Chen
HKU

My theory group on [strongly correlated] quantum matter

Graduate students:



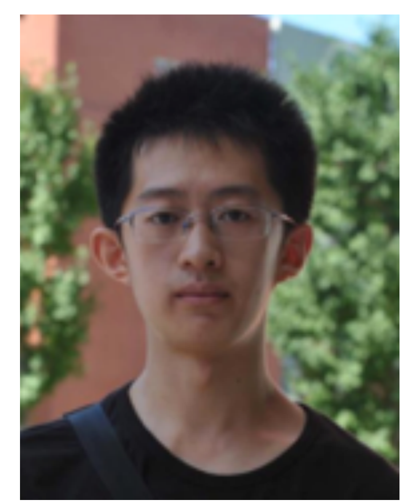
Yao-Dong Li
(Fudan -> UCSB)
Left 2017



Xu-Ping Yao
(Fudan)

Postdocs:

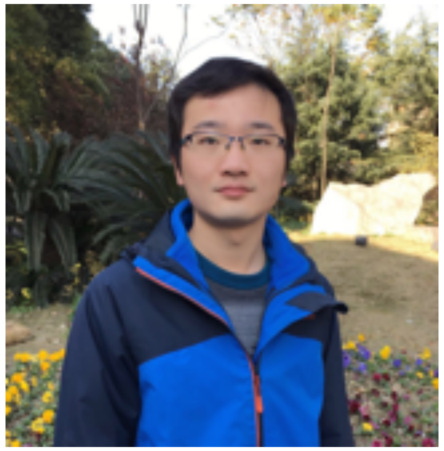
Changle Liu
（Fudan）
Joined 2017



Fei-Ye Li
（Fudan）

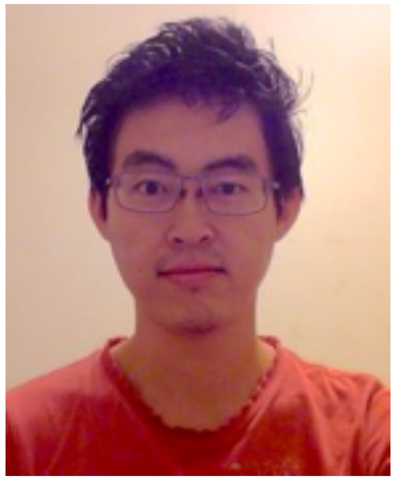
My NEW group on [strongly correlated] quantum matter

Graduate students:

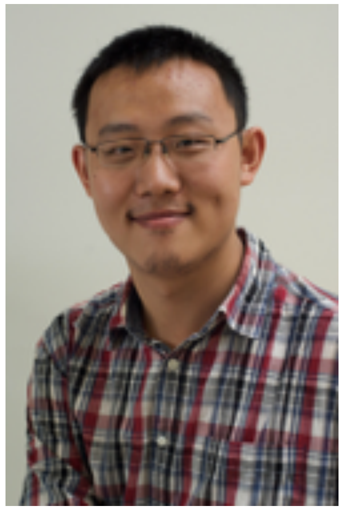


Xu-Ping Yao (HKU)

Postdocs:



Xiao-Tian Zhang
(PKU->HKU)

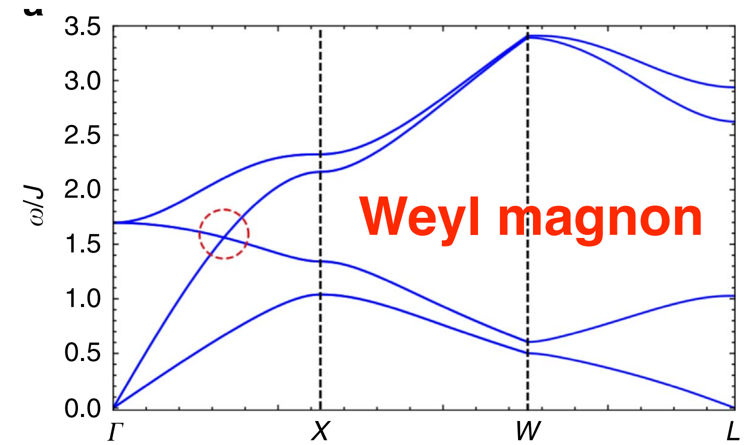


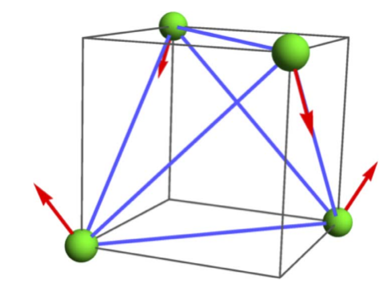
Jianlong Fu
(UMN->HKU),
Shared with Chenjie Wang’s group

Some recent topics out of my group (incomplete)

- **Topological Weyl magnons** in ordered antiferromagnet

$$H = J\sum_{\langle ij\rangle\in \mathrm{u}} \mathbf{S}_i\cdot\mathbf{S}_j + J'\sum_{\langle ij\rangle\in \mathrm{d}} \mathbf{S}_i\cdot\mathbf{S}_j + D\sum_i(\mathbf{S}_i\cdot\hat{\mathbf{z}}_i)^2$$

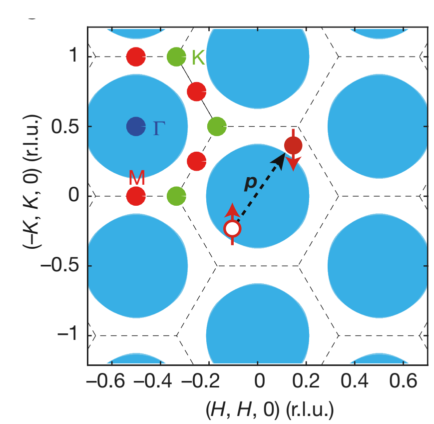


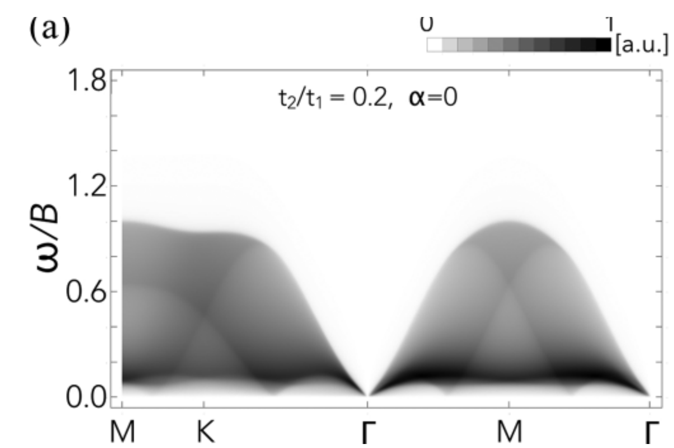


- **Spin liquid & spinon Fermi surface** in YbMgGaO4

$$\boldsymbol{S}_{\boldsymbol{r}} = \frac{1}{2}\sum_{\alpha,\beta} f^{\dagger}_{\boldsymbol{r}\alpha}\boldsymbol{\sigma}_{\alpha\beta} f_{\boldsymbol{r}\beta},$$

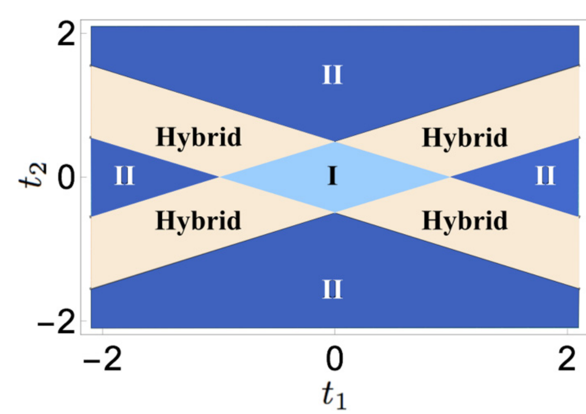
$$H_{\mathrm{MF}} = -\sum_{(\boldsymbol{r}\boldsymbol{r}')}\sum_{\alpha\beta}[\, t_{\boldsymbol{r}\boldsymbol{r}',\alpha\beta} f^{\dagger}_{\boldsymbol{r}\alpha} f_{\boldsymbol{r}'\beta} + \mathrm{H.c.}\,],$$

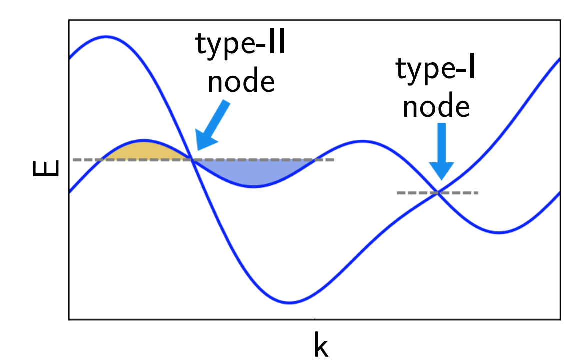




- **Hybrid Weyl semimetal**

$$H = \sum_j[-t_x\boldsymbol{c}_j^{\dagger}\sigma_x\boldsymbol{c}_{j+\hat{x}} - t_y\boldsymbol{c}_j^{\dagger}\sigma_x\boldsymbol{c}_{j+\hat{y}} - t_z\boldsymbol{c}_j^{\dagger}\sigma_x\boldsymbol{c}_{j+\hat{z}}$$
$$- it'_y\boldsymbol{c}_j^{\dagger}\sigma_y\boldsymbol{c}_{j+\hat{y}} - it'_z\boldsymbol{c}_j^{\dagger}\sigma_z\boldsymbol{c}_{j+\hat{z}} + \mathrm{H.c.}] + m\boldsymbol{c}_j^{\dagger}\sigma_x\boldsymbol{c}_j.$$

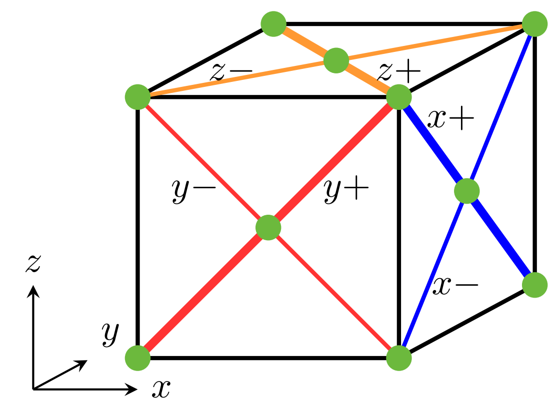




Some recent topics out of my group (incomplete)

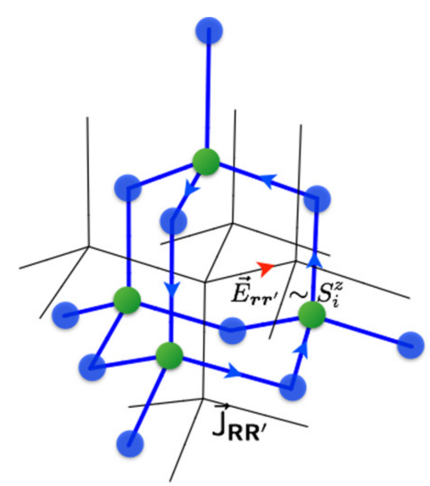
- **Kitaev materials based** on rare-earth magnets

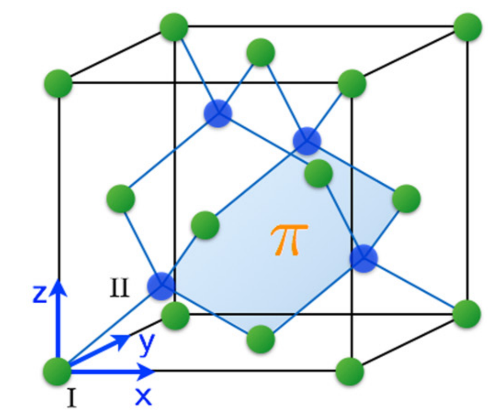
$$H=\sum_{\langle ij\rangle_{\gamma\pm}}\left[J\,\mathbf{S}_i\cdot\mathbf{S}_j+K S_i^{\gamma}S_j^{\gamma}\pm F\left(S_i^{\alpha}S_j^{\beta}+S_i^{\beta}S_j^{\alpha}\right)\right],$$



- **Spinon and magnetic monopoles in pyrochlore quantum spin ice**

$$T_{\mu}^{m}T_{\nu}^{m}\left(T_{\mu}^{m}\right)^{-1}\left(T_{\nu}^{m}\right)^{-1}=e^{i\pi}=-1.$$

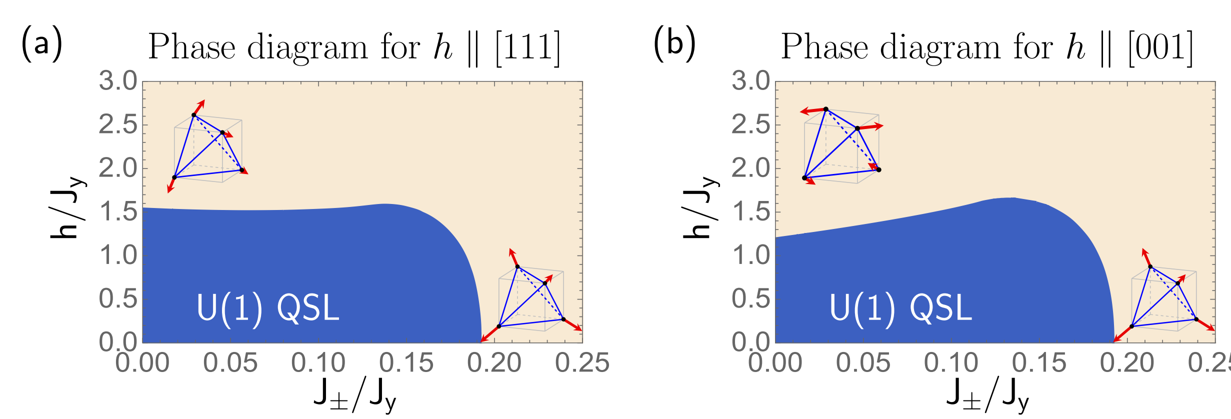




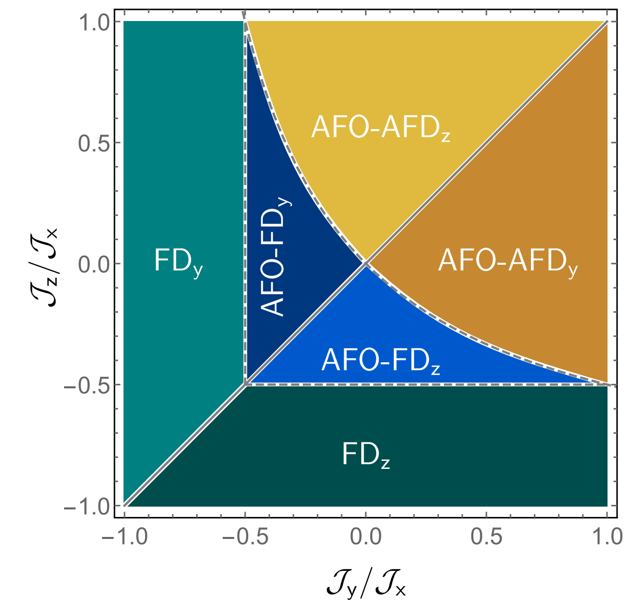
- **Symmetry enriched U(1) topological order** in 3D

$$H=\sum_{\langle ij\rangle}\sum_{\mu=x,y,z}\tilde{J}_{\mu}\tilde{\tau}_i^{\mu}\tilde{\tau}_j^{\mu}-\sum_i h\,(\hat{n}\cdot\hat{z}_i)\,\tau_i^z,$$

$$H_{\rm sim}=\sum_{\mathbf{r}}\frac{J_y Q_{\mathbf{r}}^2}{2}-\sum_{\mathbf{r}}\sum_{\mu\neq\nu}J_{\pm}\Phi^{\dagger}_{\mathbf{r}+\eta_{\mathbf{r}}\mathbf{e}_{\mu}}\Phi_{\mathbf{r}+\eta_{\mathbf{r}}\mathbf{e}_{\nu}}s^{-\eta_{\mathbf{r}}}_{\mathbf{r},\mathbf{r}+\eta_{\mathbf{r}}\mathbf{e}_{\mu}}$$
$$\times\, s^{+\eta_{\mathbf{r}}}_{\mathbf{r},\mathbf{r}+\eta_{\mathbf{r}}\mathbf{e}_{\nu}}-\sum_{\langle\mathbf{rr'}\rangle}\frac{h}{2}(\hat{n}\cdot\hat{z}_i)(\Phi^{\dagger}_{\mathbf{r}}\Phi_{\mathbf{r'}}s^{+}_{\mathbf{rr'}}+\text{H.c.}).$$



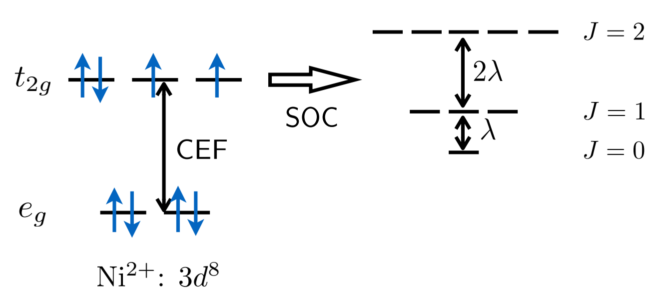
Some recent topics out of my group (incomplete)

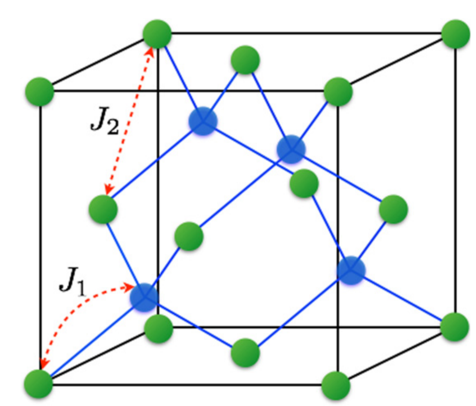


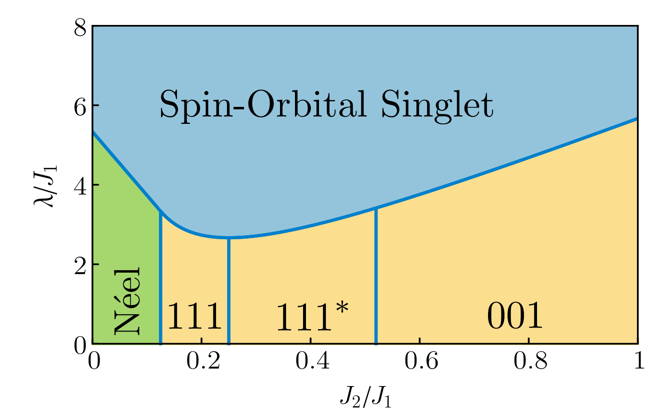
- **Hidden multipolar orders** in quantum magnets

$$H_0 = \sum_{\langle \mathbf{r}\mathbf{r}' \rangle} \left[J_x \tau^x_{\mathbf{r}} \tau^x_{\mathbf{r}'} + J_y \tau^y_{\mathbf{r}} \tau^y_{\mathbf{r}'} + J_z \tau^z_{\mathbf{r}} \tau^z_{\mathbf{r}'} + J_{yz} \left(\tau^y_{\mathbf{r}} \tau^z_{\mathbf{r}'} + \tau^z_{\mathbf{r}} \tau^y_{\mathbf{r}'} \right) \right].$$

- **Quantum criticality** from spin-orbit entanglement for 3d antiferromagnets

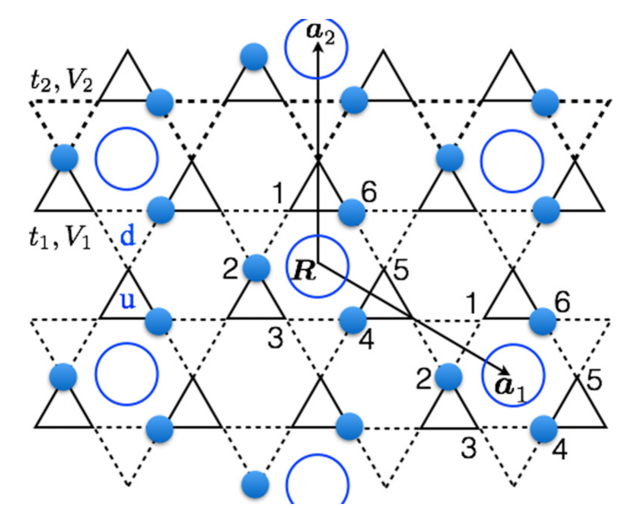




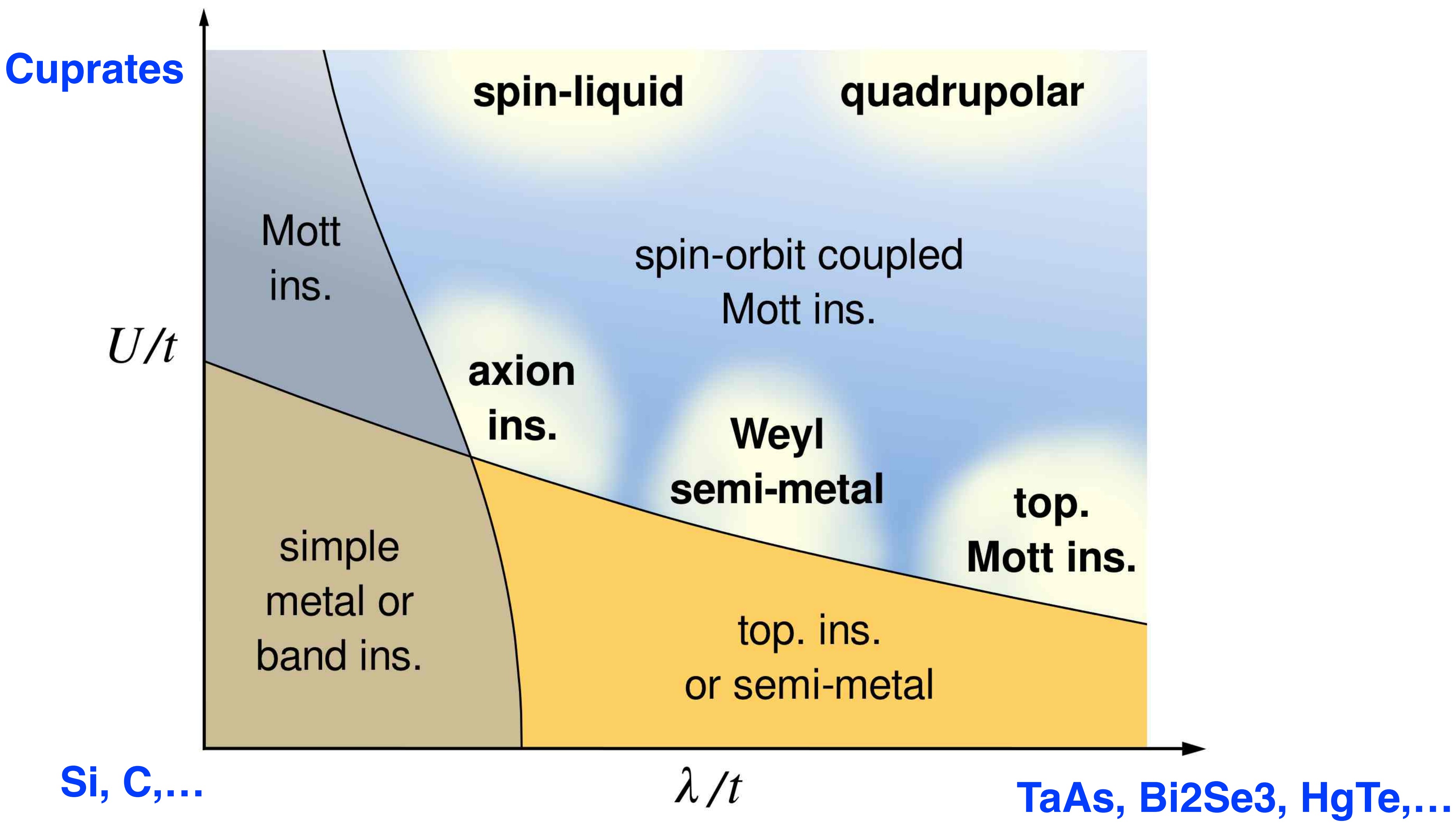


- **Cluster Mott insulators**

$$H = -\sum_{\langle ij \rangle \in \mathrm{u}} (t_1 c^\dagger_{i\sigma} c_{j\sigma} + \mathrm{H.c.}) - \sum_{\langle ij \rangle \in \mathrm{d}} (t_2 c^\dagger_{i\sigma} c_{j\sigma} + \mathrm{H.c.}) + \sum_{\langle ij \rangle \in \mathrm{u}} V_1 n_i n_j + \sum_{\langle ij \rangle \in \mathrm{d}} V_2 n_i n_j + \sum_i U n_{i\uparrow} n_{i\downarrow},$$

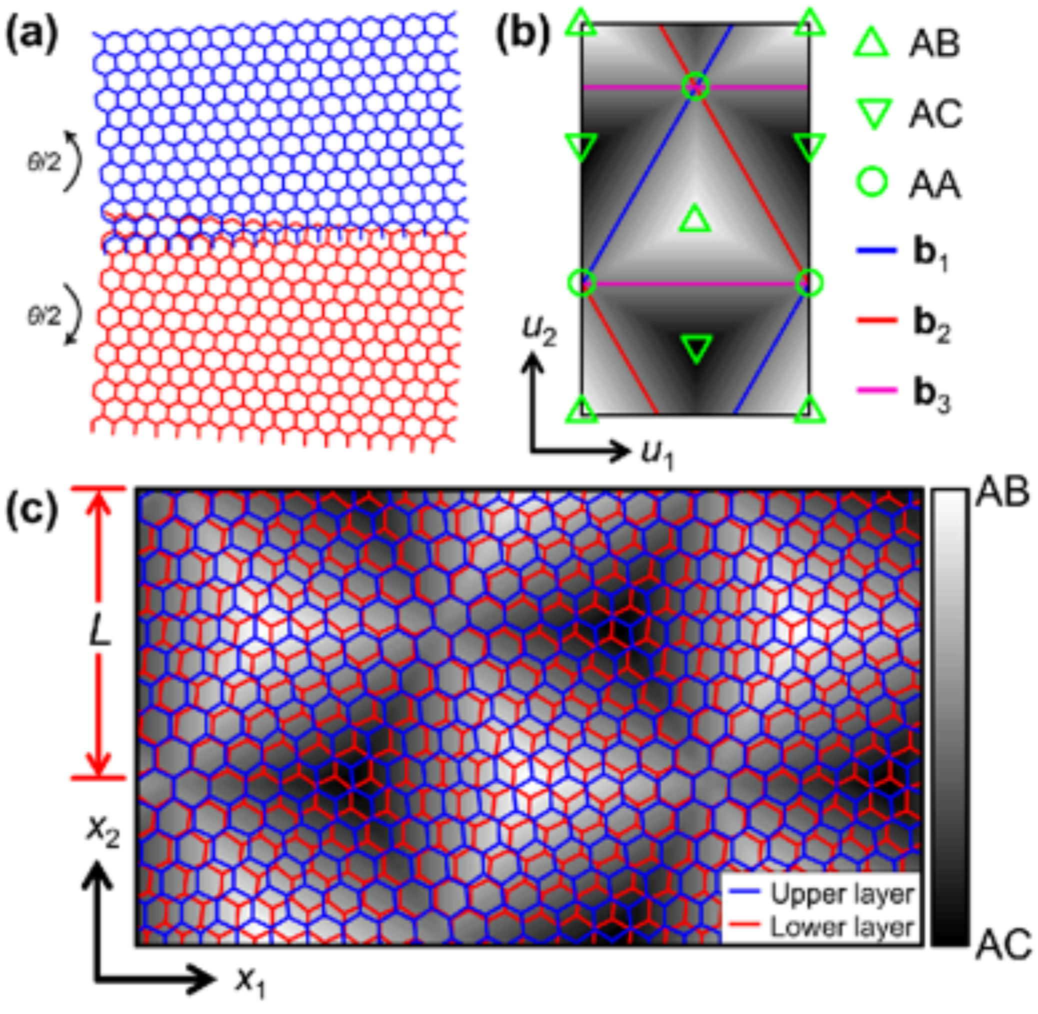


Spin-orbit-coupled correlated matter

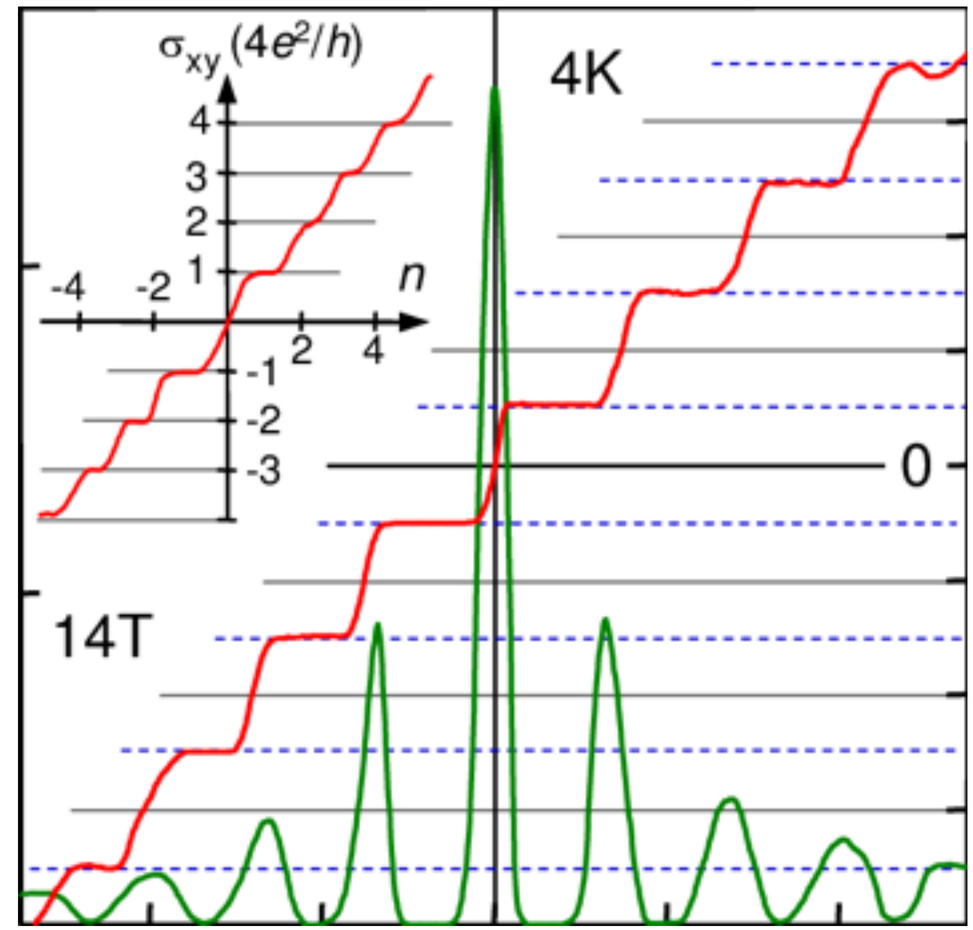


Most comprehensive phase diagram:
contain almost all condensed matter materials

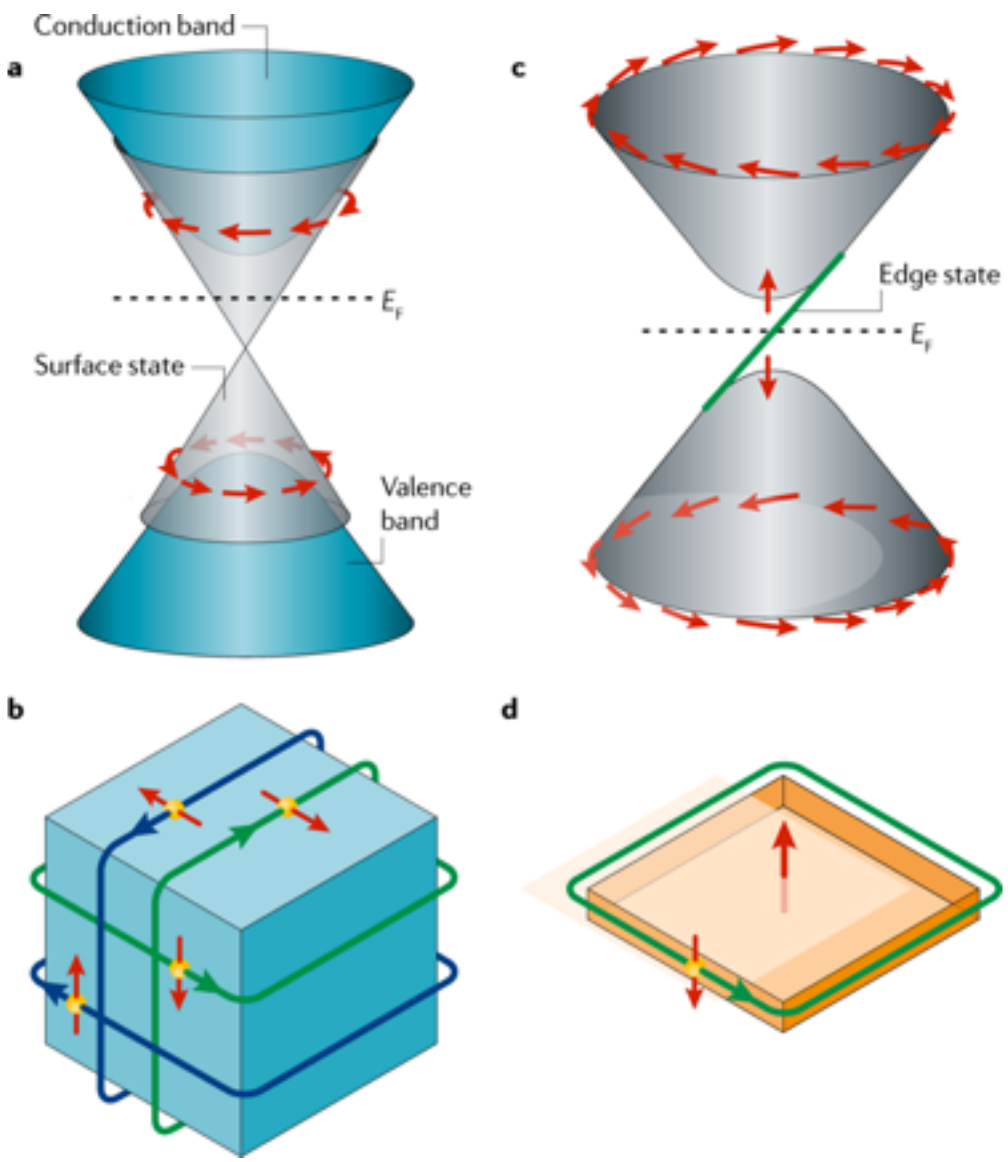
W Witczak, **Gang Chen**, YB Kim, L Balents,
Annual Review of Condensed Matter Physics, 2014



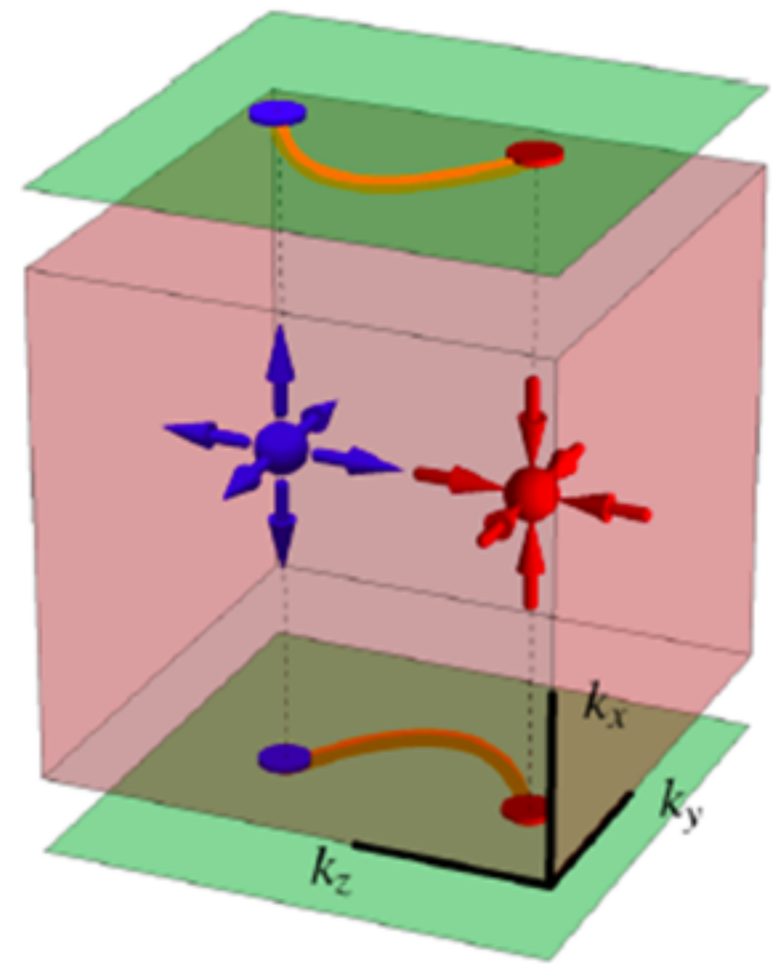
twisted bilayer graphene:
not trivial !
figure in Shuyang Dai, etc



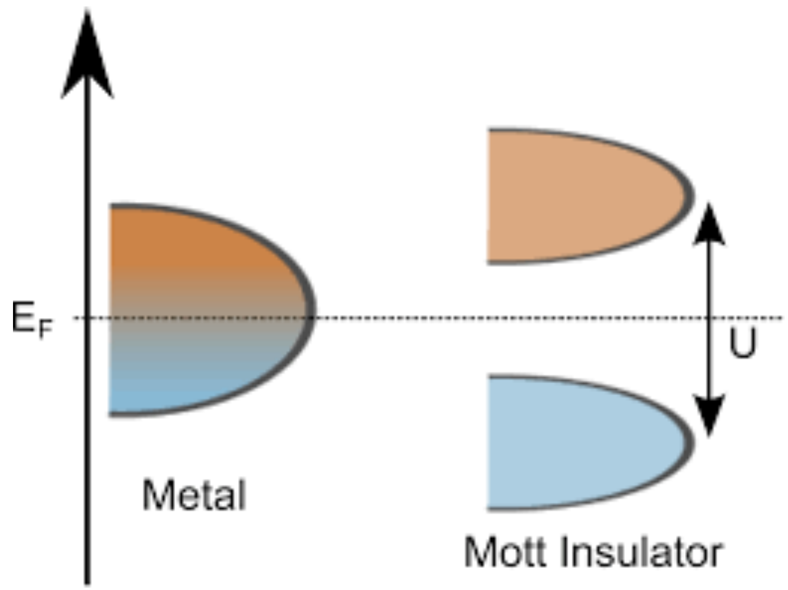
graphene quantum Hall

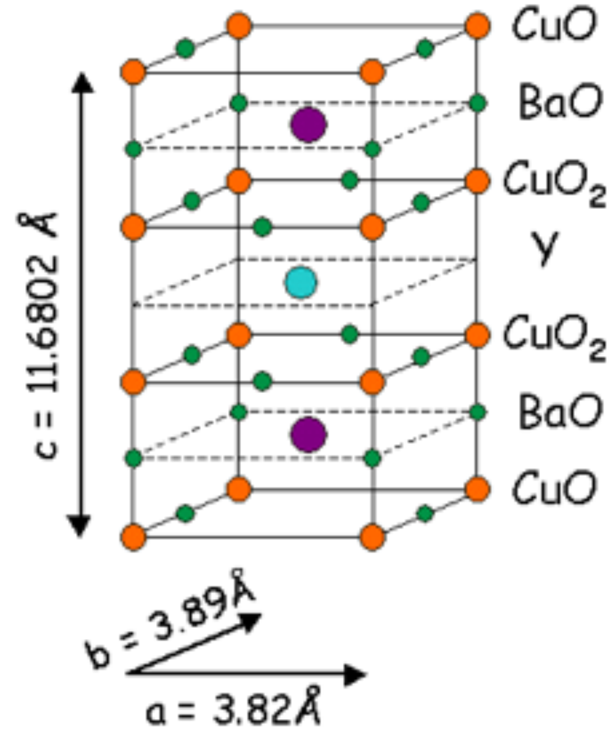


Topological insulator

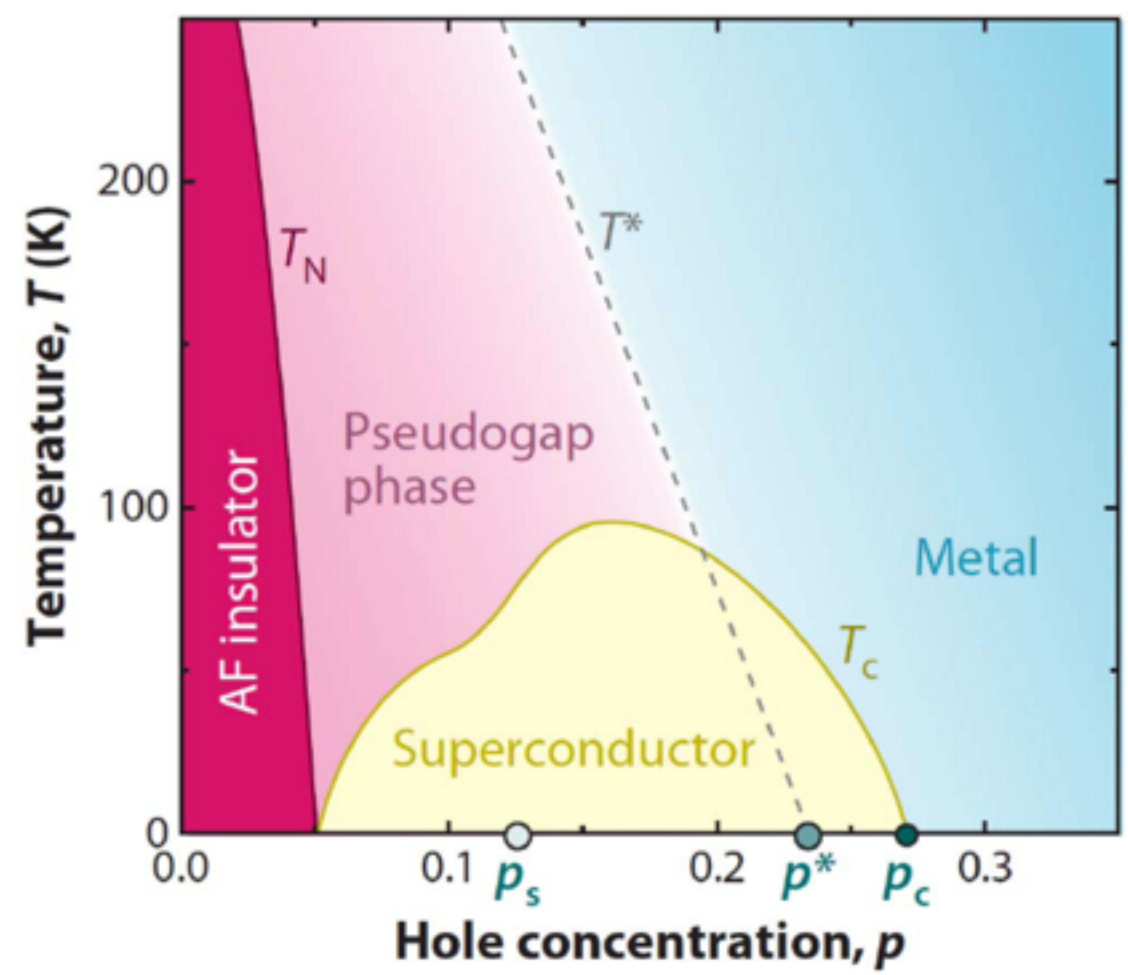


Weyl semimetal

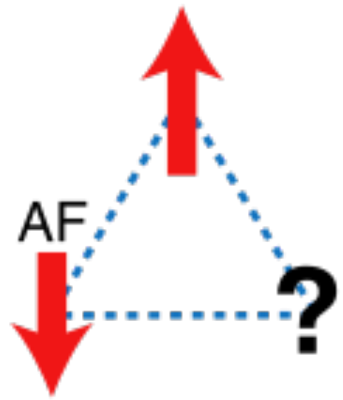




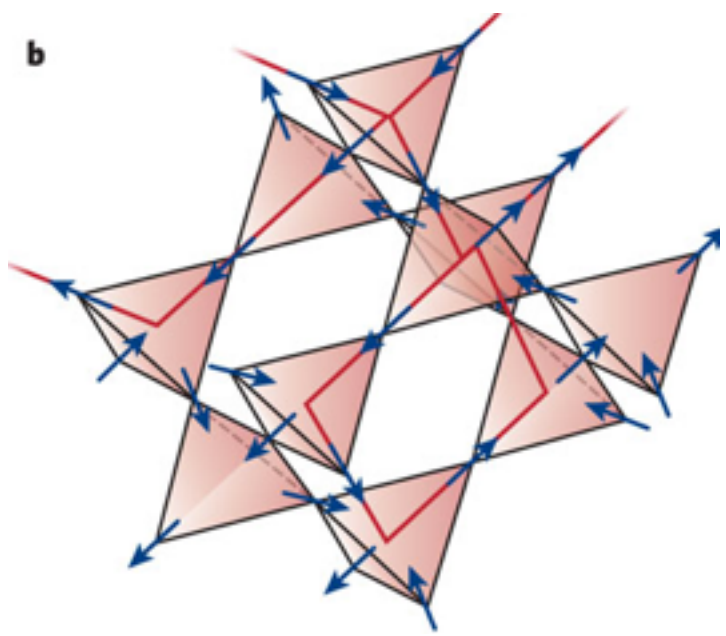
High temperature superconductivity



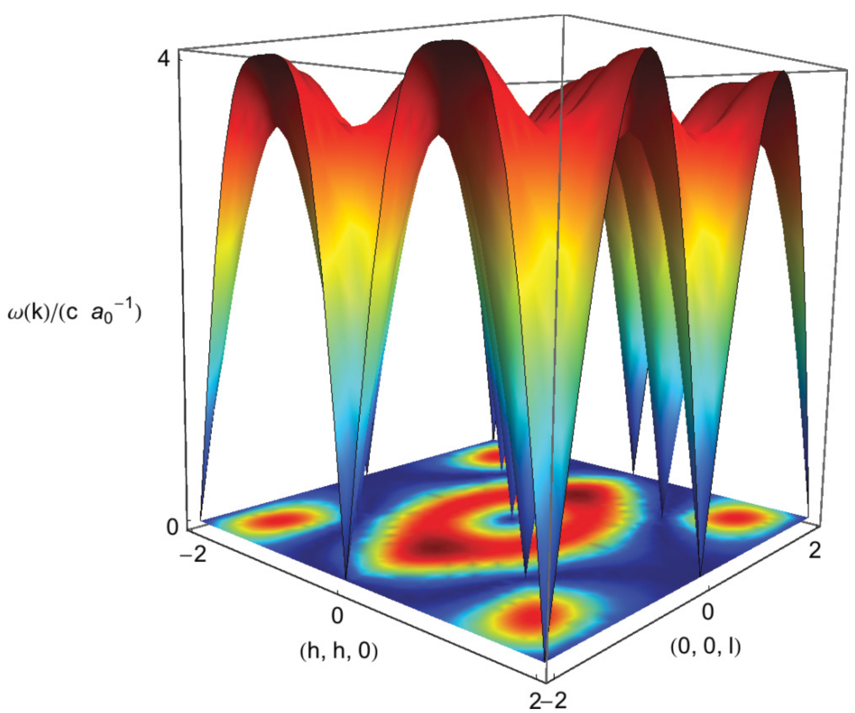
Quantum and frustrated magnetism



Geometrical frustration

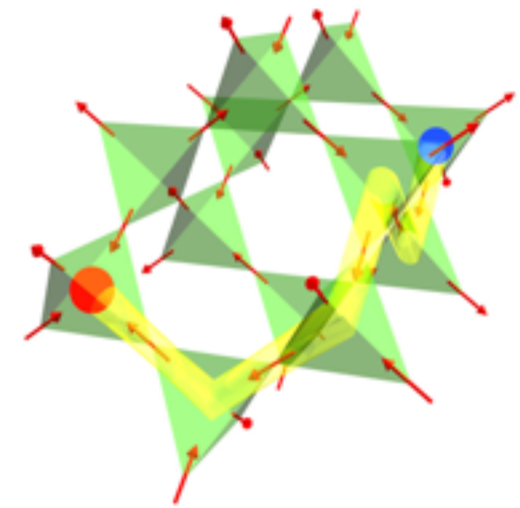


Pyrochlore spin ice
figure courtesy (Balents)



Emergent gauge photon
figure courtesy (Benton)

Equivalence of “notations”: three excitations



Excitations (notation 1)	Excitations (notation 2)
Spinon	Magnetic monopole
“Magnetic monopole”	Electric monopole
Gauge photon	Gauge photon

has classical analogue

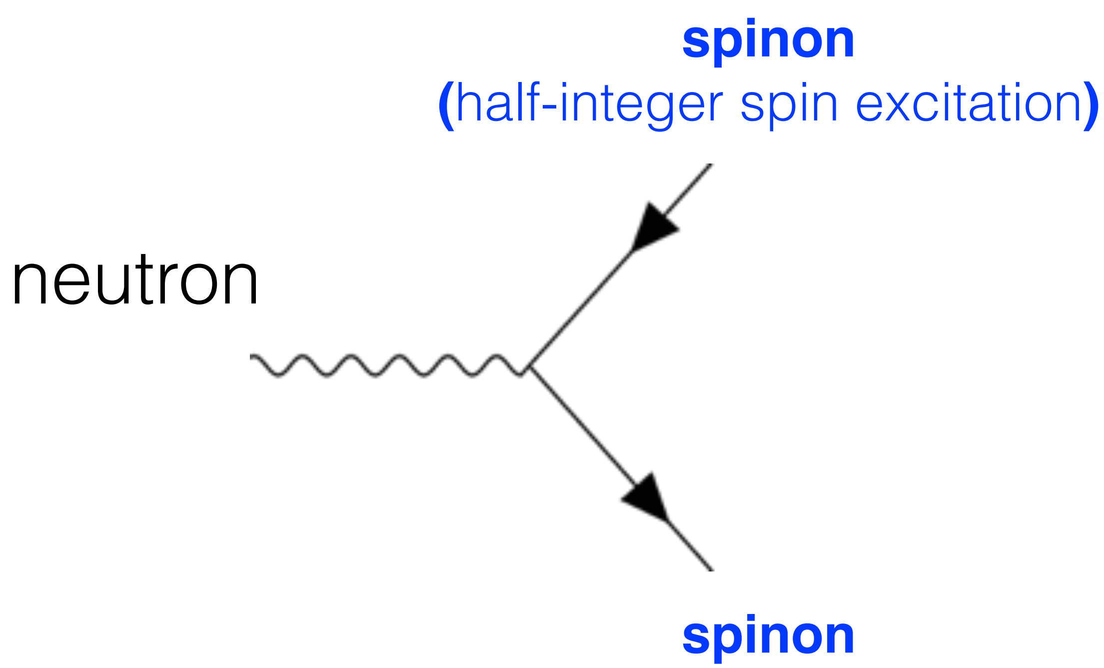
purely quantum, no classical analogue

Gang Chen, PhysRevB, 96, 195127 (2017)

“Magnetic monopole” is probably closer in spirit to **Dirac’s monopole (1931).**
One has to confirm that “magnetic monopole” is emergent excitation, rather than a fictitious particle.

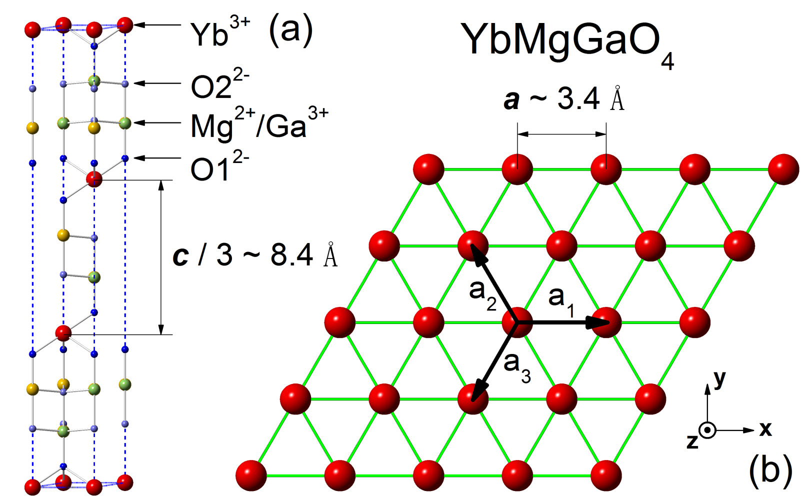
What piece of experimental info indicates these exotic and emergent particles?

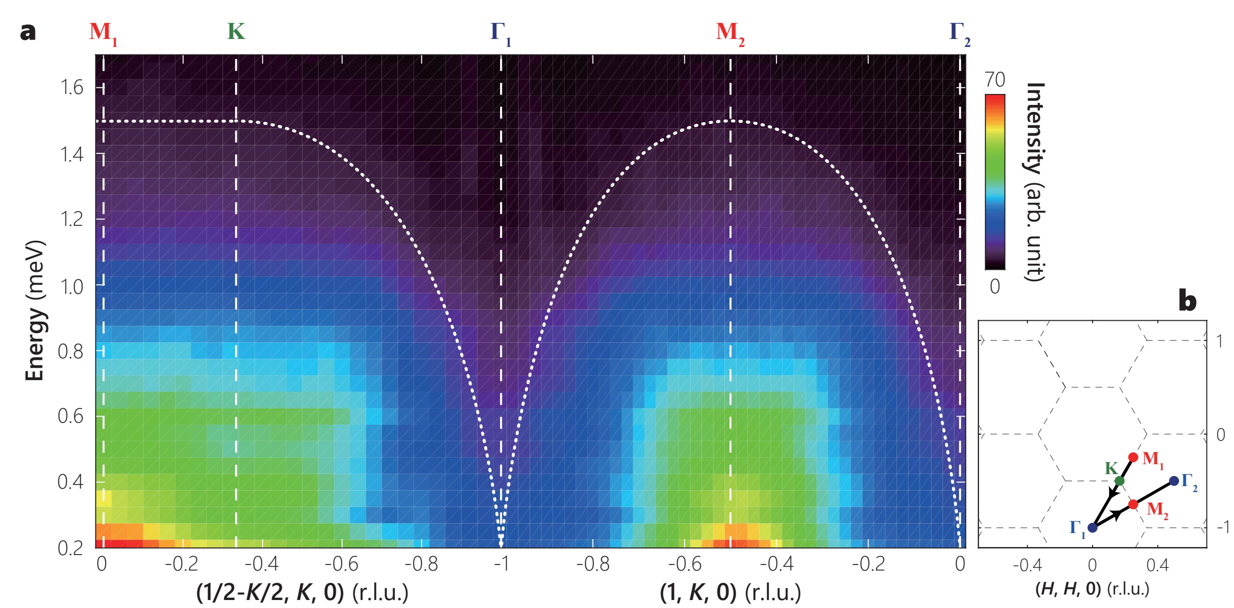
Spin liquid: fractionalization !



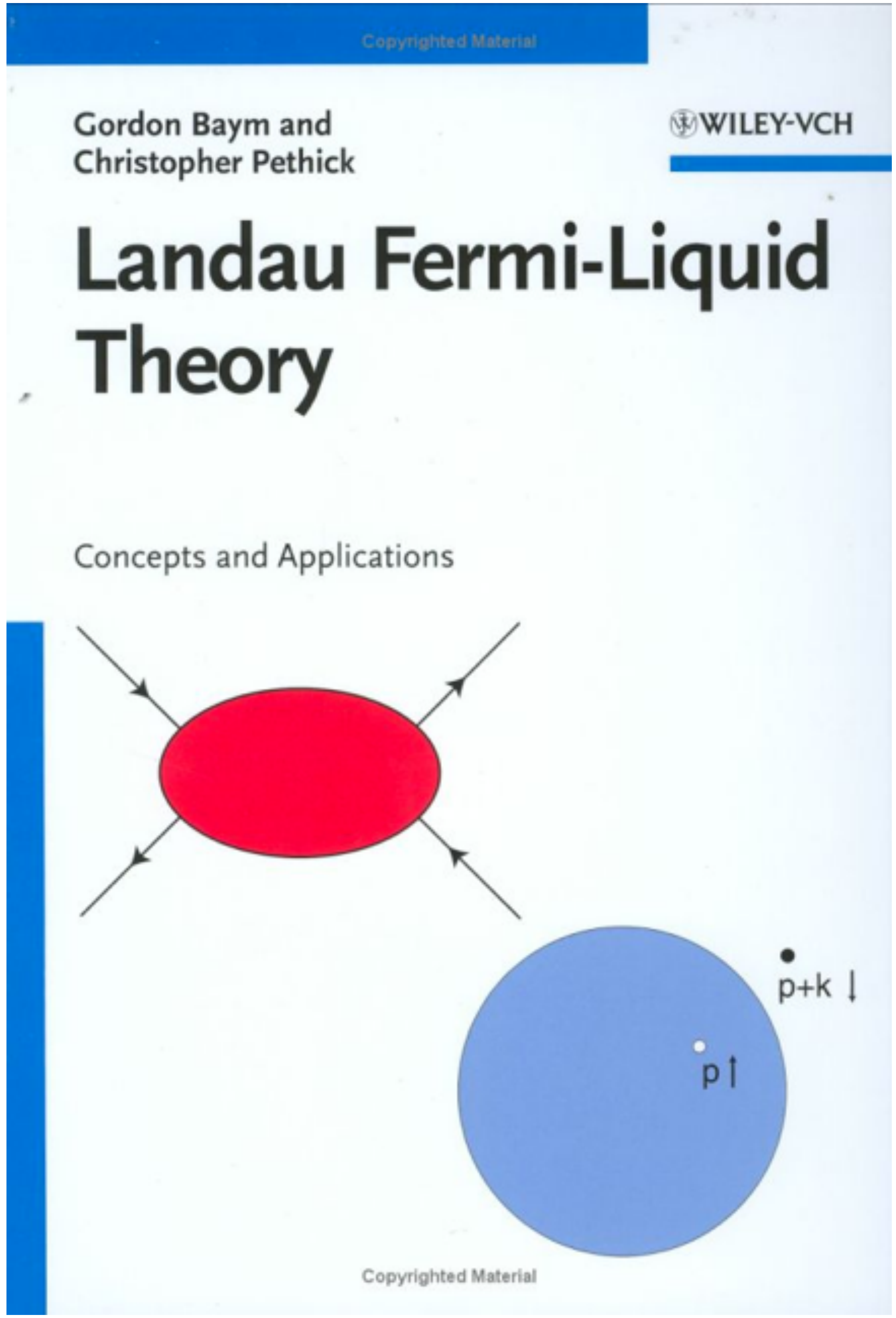
$$P = q_1 + q_2$$

$$E = \omega(q_1) + \omega(q_2)$$





With Qingming Zhang, Jun Zhao
2015-2018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p ↑
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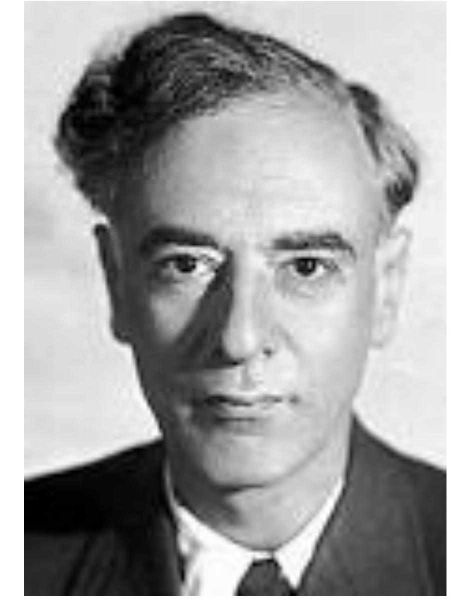
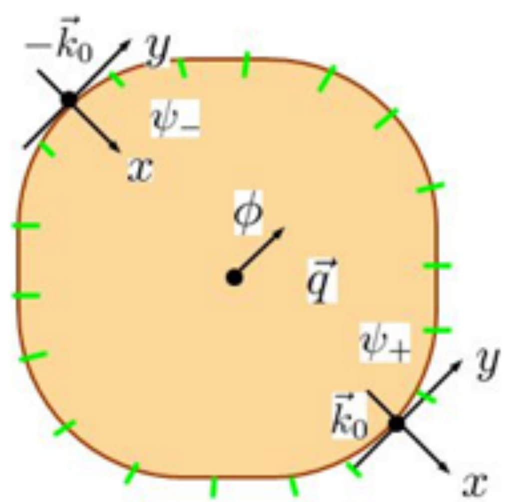


Two-patch theory

Non-Fermi liquid theory

- For each $\hat{q}$ expand the fermion fields about two opposite points on the Fermi surface, $\vec{k}_0$ and $-\vec{k}_0$.



$$L_\psi = \psi^\dagger_{+\sigma}\left(\partial_\tau + v_F(-i\partial_x - \frac{\partial_y^2}{2K})\right)\psi_{+\sigma} + \psi^\dagger_{-\sigma}\left(\partial_\tau + v_F(i\partial_x - \frac{\partial_y^2}{2K})\right)\psi_{-\sigma}$$

$$L_\phi = \frac{1}{2e^2}(\partial_y\phi)^2 + \frac{r}{2}\phi^2$$

$$L_{int} = v_F\phi(\psi^\dagger_{+\sigma}\psi_{+\sigma} + \psi^\dagger_{-\sigma}\psi_{-\sigma})$$

- Key assumption: can neglect coupling between patches.

curtesy from Sung-Sik Lee, PA Lee, M. Metlitski

Large N: Polchinski (94), Altshuler, Ioffe and Millis (94).
N fermions coupled to gauge field. $e \to e/\sqrt{N}$

$D = \dfrac{1}{i\frac{\nu}{q} + \chi q^2}$

$\Sigma \approx \frac{1}{N}\omega^{2/3}$, no $\vec{k}$ dependence

Minimal 2 patch model. Sung-Sik Lee, (PRB80 165102 (09)

$$\Gamma = \sum_j \int dk\left[i\frac{c}{N}\mathrm{sgn}(k_0)|k_0|^{2/3} + ik_0 + v_x k_x + v_y k_y^2\right]\psi_j^*(k)\psi_j(k) + \int dk\left[\gamma\frac{|k_0|}{|k_y|} + k_0^2 + k_x^2 + k_y^2\right]a^*(k)a(k) + \frac{e}{\sqrt{N}}\sum_j\int dkdq\ a(q)\psi_j^*(k+q)\psi_j(k). \qquad (2)$$

Plus opposite patch with e -> -e
Note curvature of patch is kept.

My group always welcomes new members !