Electrical detection of Spin liquids in double moire layer

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Ya-Hui Zhang and Ashvin Vishwanath, arxiv: 2005.12925

Outline

I. Review of two recent experimental progress

(1) Exciton condensation in Quantum Hall bilayer

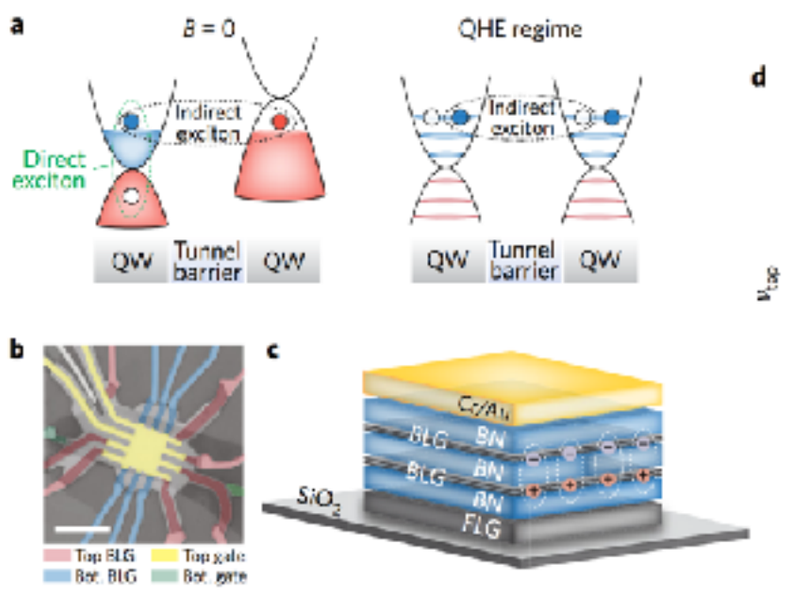
(2) Correlated insulator in a moire superlattice

II. Propose moire bilayers

III. Certain spin liquids can be easily detected

IV. Thereotical evidence for these spin liquids

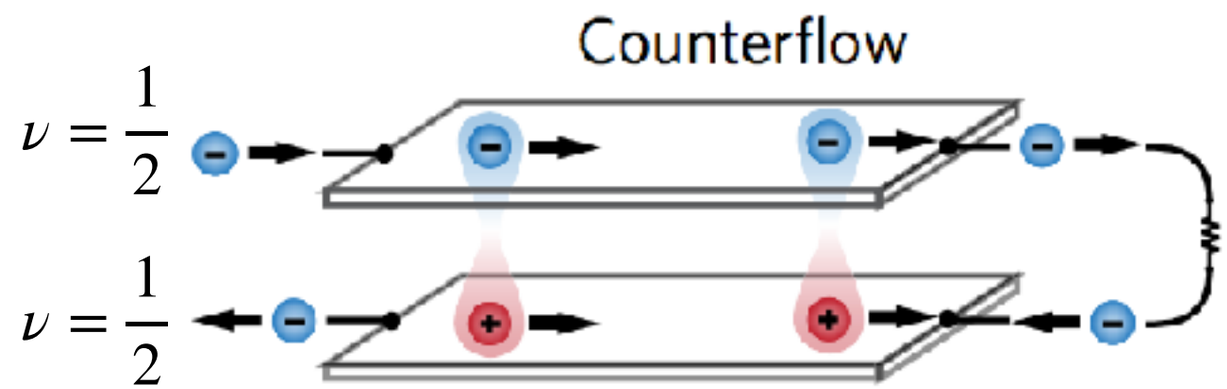
Exciton condensation in QH bilayer:



Jia Li,…, C.R.Dean, Nature Physics (2017)

Xiaomeng Liu,…, Philip Kim, Nature Physics (2017)

See also review by J.P. Eisenstein (2014)



Measurement of Exciton transport

KT transition was confirmed !

“Spin” in QH bilayers

Two quantum numbers:

Distance d: 1 nm; magnetic length l_B: 10 nm

$$Q = N_{top} + N_{bottom}$$

$$S_z = N_{top} - N_{bottom}$$

Symmetry

$U(1)_c$: Conservation of Q

$U(1)_s$: Conservation of S_z

Easy-plane anisotropy: SU(2) spin rotation is broken

Interaction: $H_V = UN_{top}N_{top} + UN_{bottom}N_{bottom} + 2U'N_{top}N_{bottom} = UQQ + \delta US_zS_z$

$$U \sim \frac{e^2}{\epsilon l_B} \qquad U' \sim \frac{e^2}{\epsilon\sqrt{l_B^2 + d^2}} \qquad \delta \sim \frac{U - U'}{U} \sim (\frac{d}{l_B})^2$$

SU(2) spin rotation is recovered at d/l_B<<1 limit.

A unified picture

bilayer	"spin" language	"exciton" language
$c^\dagger_{botom}\|0>$	$\|\downarrow>$	$\|0>$
$c^\dagger_{top}\|0>$	$\|\uparrow>$	$\|1> = b^\dagger\|0>$
$\frac{1}{2}(n_{top} - n_{bottom})$	S_z	$n_b - \frac{1}{2}$
$c^\dagger_{top}c_{bottom}$	$S^\dagger$	$b^\dagger$
Counterflow current: $I_{top} - I_{bottom}$	spin current	exciton current
Phase I	XY FM: $\langle S_x \rangle \neq 0$	exciton condensation $\langle b \rangle \neq 0$
Phase II	Neel order	super solid
Phase III	Valence bond solid	Crystalized insulator
Phase IV	chiral spin liquid	exciton FQHE
Phase V	spinon Fermi surface	exciton metal

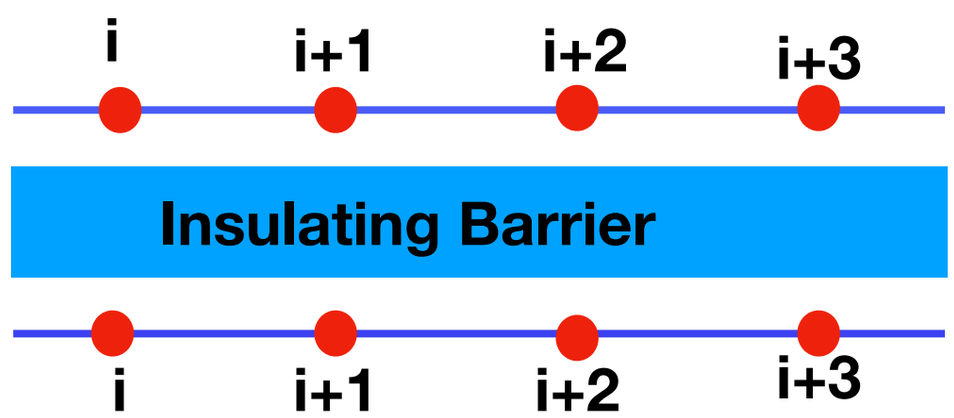
From quantum Hall bilayer to Hubbard bilayer

In Landau level, spin correlation is ferromagnetic (QHFM)

To have antiferromagnetic coupling: lattice Hubbard model

Lattice constant: a_M

Hubbard model



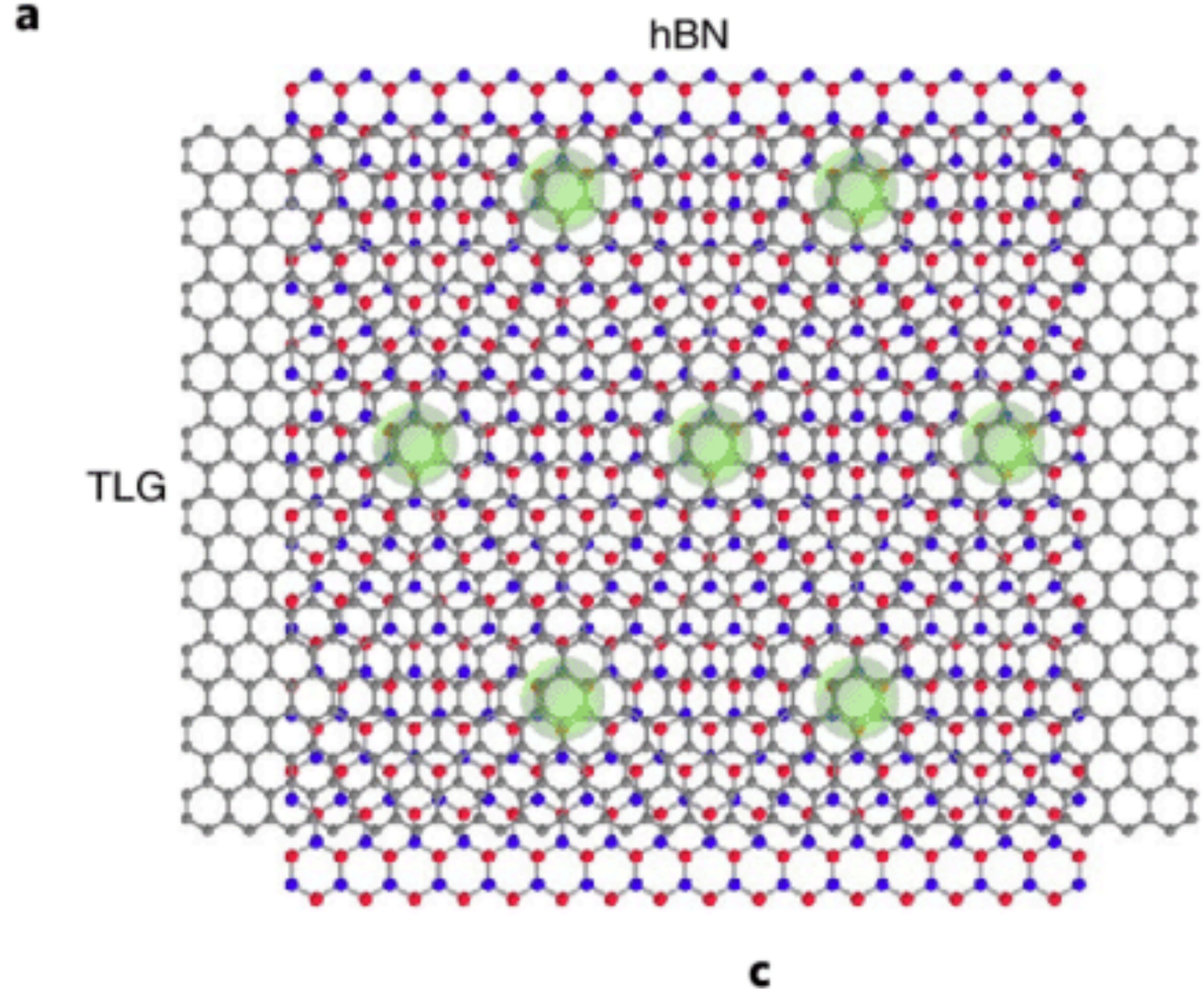
Hubbard model

$$U \sim \frac{e^2}{\epsilon a_M} \quad U' \sim \frac{e^2}{\epsilon\sqrt{a_M^2 + d^2}}$$

$$\delta \sim \frac{U - U'}{U} \sim (\frac{d}{a_M})^2$$

In the d<<a_M limit, layer can be viewed as a "spin" with SU(2) rotation symmetry.

We need a superlattice!



Hubbard model has been realized for single moire layer:

ABC trilayer graphene aligned with hBN — Guorui Chen,…, Feng Wang, Nature Physics (2019)

TMD hetero-bilayer: TMD1 aligned with TMD2 — Kin Fai Mak, et.al, Nature (2020); Feng Wang et.al., Nature (2020)

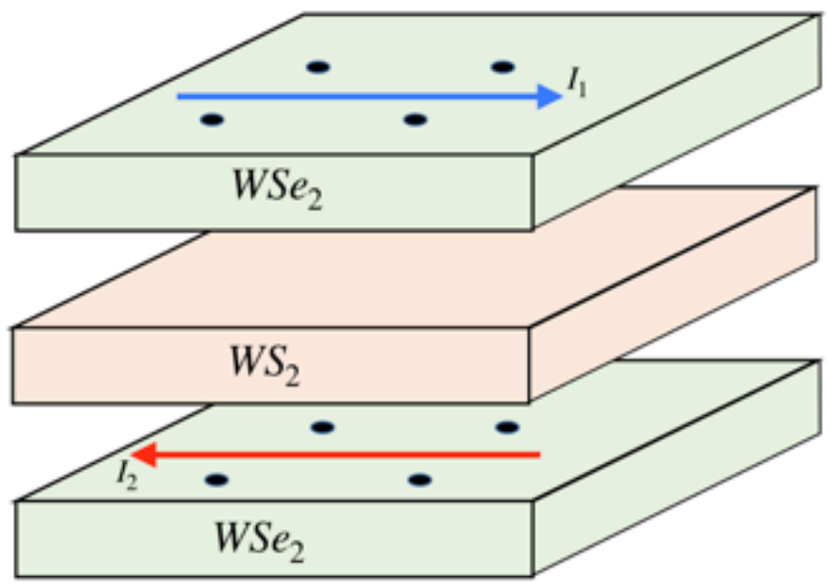
We will use two of these systems to build a moire bilayer: 1+1>2!

“Spin” in moire bilayers

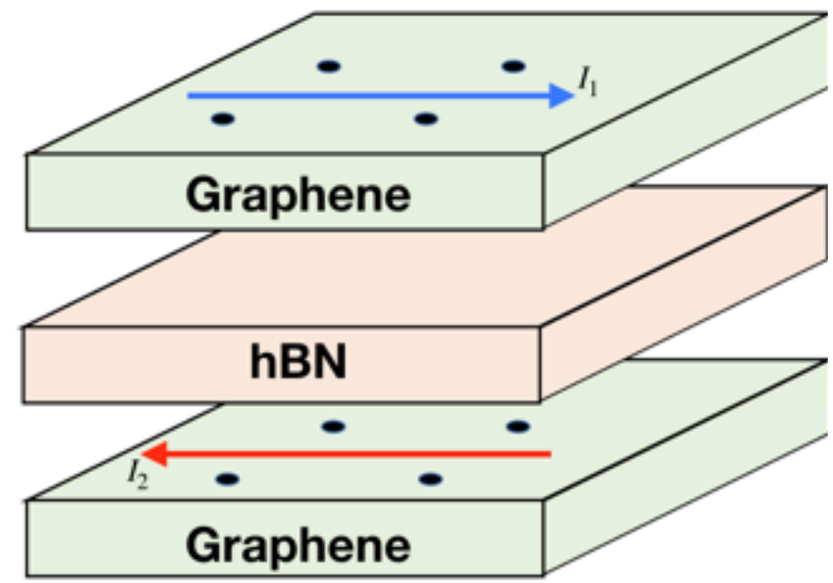
View layer as a pseudospin

Isotropic limit: $\frac{d}{a_M} \to 0$

d: 1nm ; a_M: 10 nm



Kin Fai Mak, et.al, Nature (2020);
Feng Wang et.al., Nature (2020)



Guorui Chen,…, Feng Wang, Nature Physics (2019)

A minimal model on triangular lattice:

$$H = -t \sum_{ij} c^{\dagger}_{i;\alpha} c_{i;\alpha} + U \sum_i n_i(n_i - 1) + \delta U \sum_i \rho^2_{i;z} \qquad \delta \sim (\frac{d}{a_M})^2$$

α **is flavor index : spin-layer (SU(4)) or spin-valley-layer (SU(8))**

A simplified case: two flavor model

Let us assume spin,valley are polarized. A "spin" 1/2 Hubbard model:

$$H = -t\sum_{ij} c^{\dagger}_{i;\alpha} c_{i;\alpha} + U\sum_{i} n_{top} n_{bottom} \qquad \alpha = top, bottom$$

At n_top+n_bottom=1 and U>>t limit, Mott insulator: charge is frozen

At low energy, "spin" or exciton at each site:

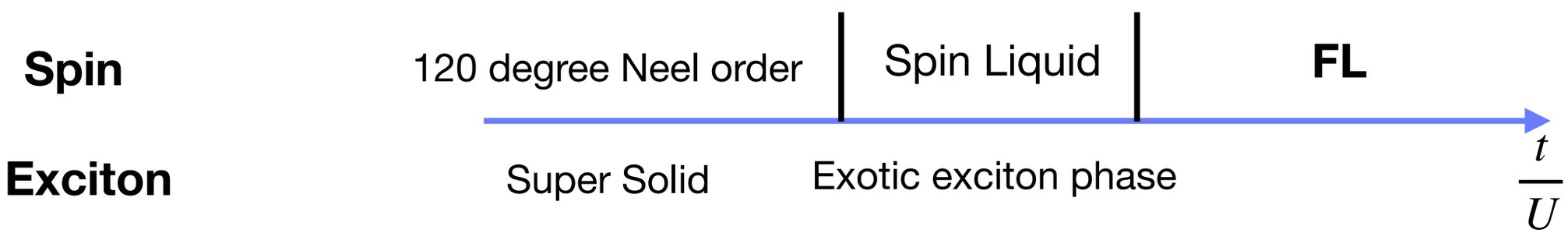
bilayer	"spin" language	"exciton" language
$c^{\dagger}_{botom}\|0>$	$\|\downarrow>$	$\|0>$
$c^{\dagger}_{top}\|0>$	$\|\uparrow>$	$\|1> = b^{\dagger}\|0>$
$\frac{1}{2}(n_{top} - n_{bottom})$	S_z	$n_b - \frac{1}{2}$
$c^{\dagger}_{top} c_{bottom}$	$S^{\dagger}$	$b^{\dagger}$
Counterflow current: $I_{top} - I_{bottom}$	**spin current**	**exciton current**

Spin model/exciton model at low energy

At U>>t and n=1, we have a spin 1/2 or a hard-core boson (exciton) at each site:

$$S_z \leftrightarrow n_b - \frac{1}{2} \quad S^\dagger \leftrightarrow b^\dagger \quad S^- \leftrightarrow b$$

Phase diagram from numerics (DMRG):



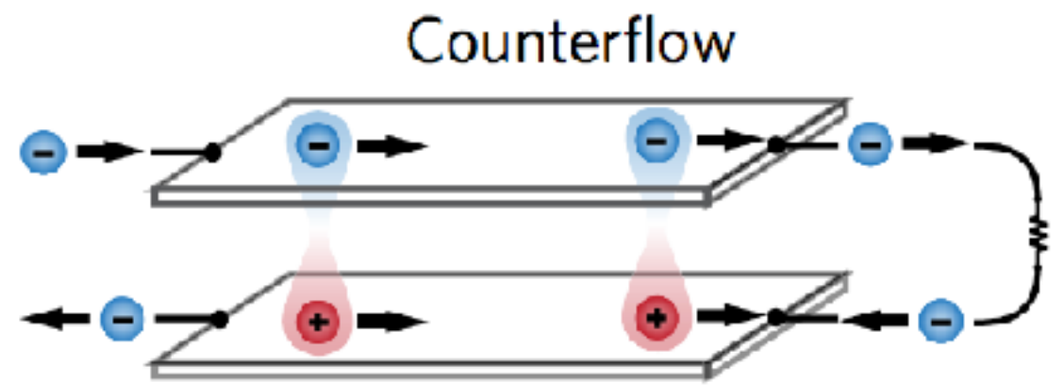
Two candidates for the weak Mott regime:

(I) Chiral Spin Liquid or Exciton FQHE

(II) Spinon Fermi surface or Exciton metal

Spin liquid in language of exciton

(I) Chiral Spin Liquid or Exciton FQHE



1/2 Laughlin state of exciton

Couterflow transport: $\sigma_{xy} = \frac{1}{2}, \sigma_{xx} = 0$

Anyon with $\theta = \frac{\pi}{2}$ and half exciton charge

fractional quantum anomalous hall effect of exciton !

(II) Spinon Fermi Surface and Exciton metal

One exciton split to two fermions, each then forms a Fermi surface

Couterflow transport: $\rho_{xx} \sim T^{\alpha}$

Counterflow current: $I_s = I_{top} - I_{bottom}$, $V_s = V_{top} - V_{bottom}$ $\longleftrightarrow$ **spin current** $\longleftrightarrow$ **exciton current**

Phase diagram for SU(N) spin model

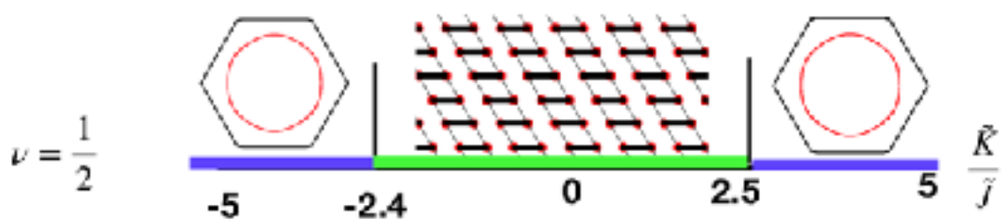
Let us add spin-valley flavors within each layer:

SU(4) or SU(8) spin model at integer $\nu_T = 1,2,3,...,N-1$

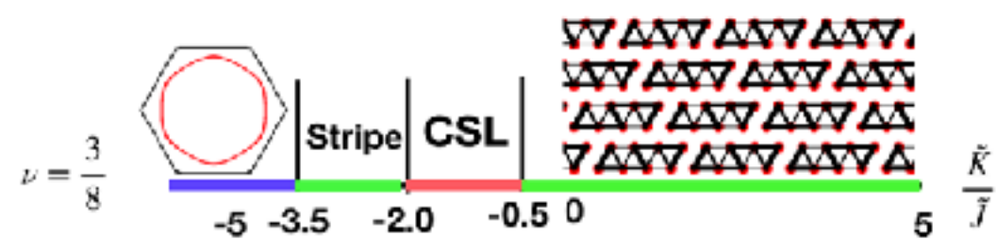
$$\nu = \frac{\nu_T}{N}$$

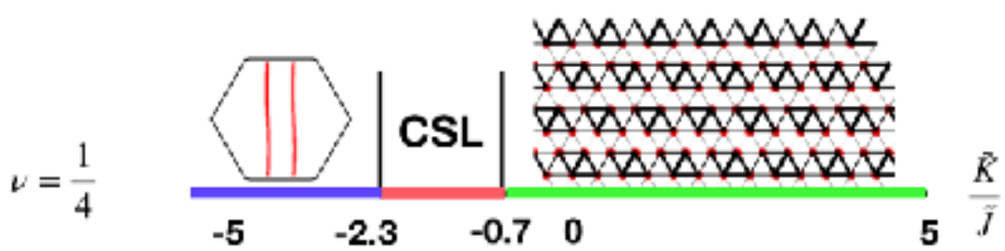
Large N mean field theory based on Abrikosov fermion:

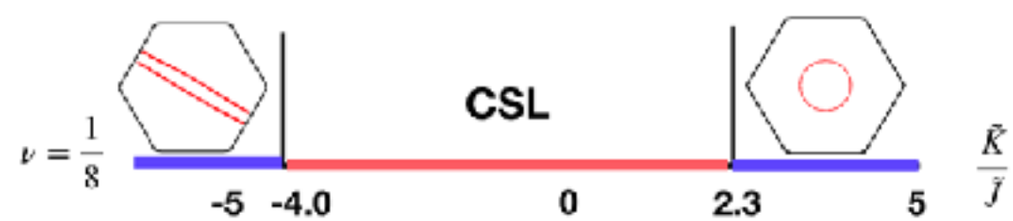
$$\frac{\tilde{K}}{\tilde{J}} \propto N\frac{t}{U}$$



exciton metal







(1) For SU(8) at ν_T =1, Heisenberg limit is a chiral spin liquid (exciton FQHE)

(2) For SU(4) at ν_T =3, weak mott regime (t/U>0.06) is a chiral spin liquid (exciton FQHE)

Still anomalous Hall effect in counter-flow transport.

Summary

I. Generalize QH bilayer to Hubbard bilayer

each layer is a moire superlattice with narrow band

II. Two promising spin liquidphases

exciton FQHE or chiral spin liquid

exciton metal or spinon Fermi surface

III. Smoking gun evidence from counter-flow transport