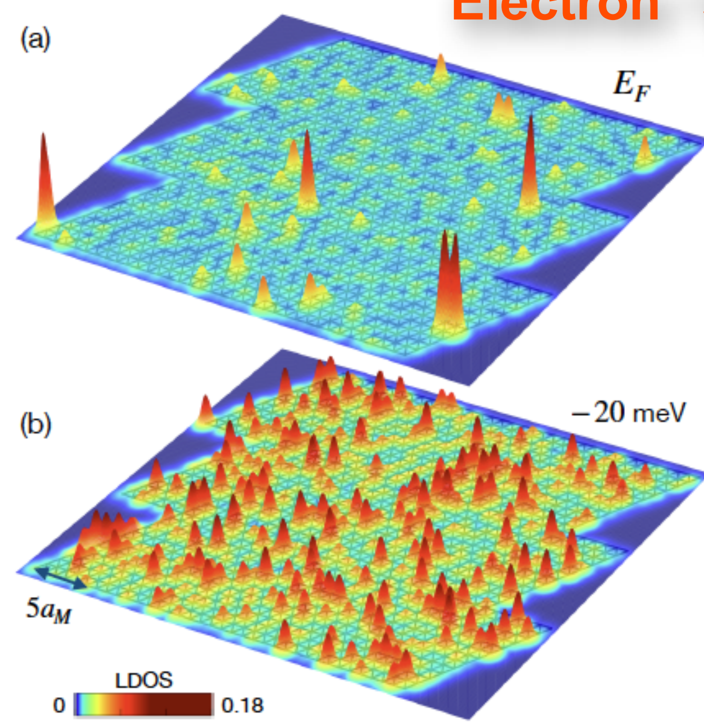
Moire-Wigner-Mott Freezing in TMD Herterobilayers

Vladimir Dobrosavljevic
Florida State University

Electron "slush"



<u>Collaborators</u>:

Yuting Tan **(FSU)**

Pak-Ki (Henry) Tsang **(FSU)**

Louk Rademaker **(Geneva)**

<u>Funding:</u> ***NSF grants:***

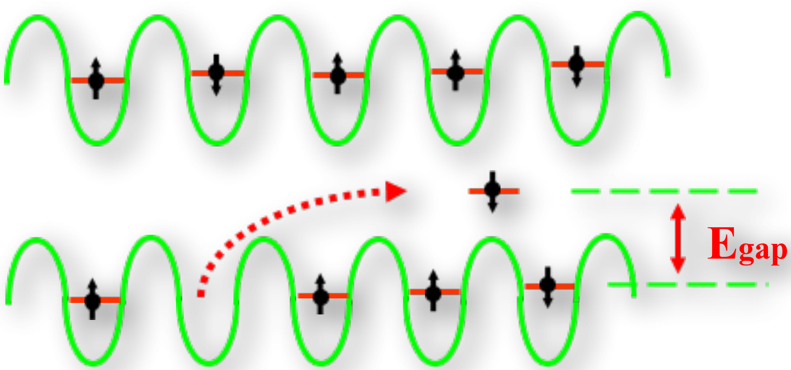
DMR-1822258
DMR-1410132
…

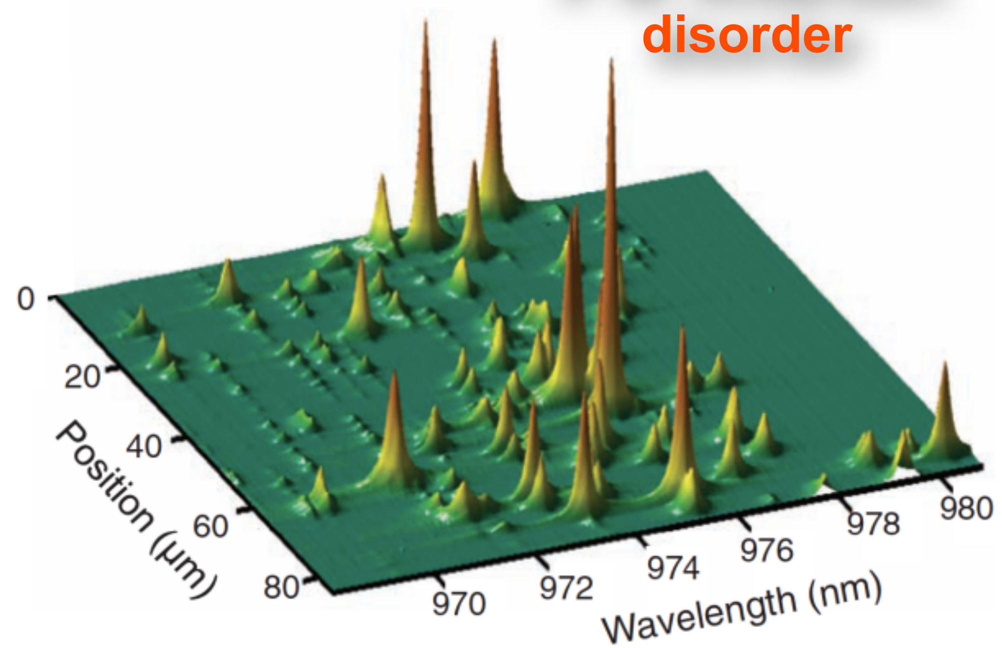
Mechanisms for Localization?

Sir Neville Mott:
interaction

Friend or Foe???

P. W. Anderson:
disorder



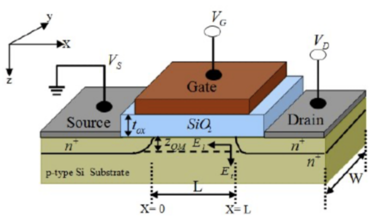


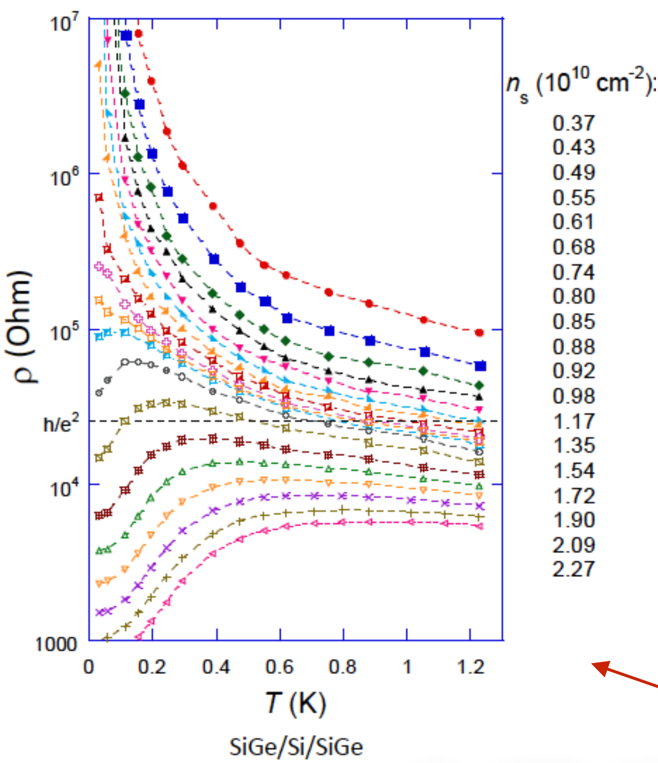
Do correlations increase or weaken (screen) disorder?

Model Mott systems

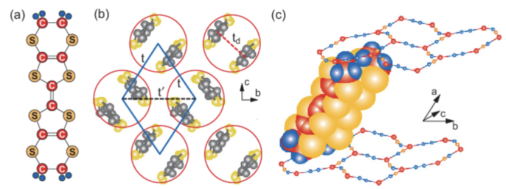
(Strong interactions - half-filled narrow bands)

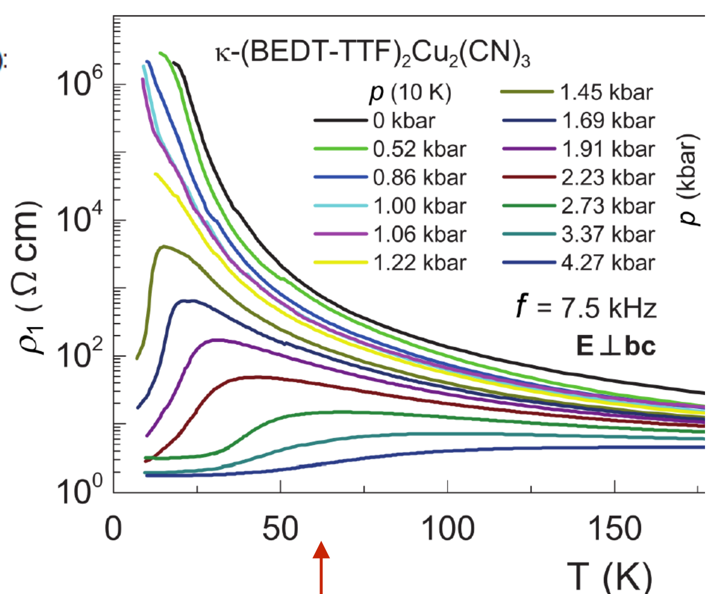
2DEG in Si/SiGe (Kravchenko, 1995-2021)



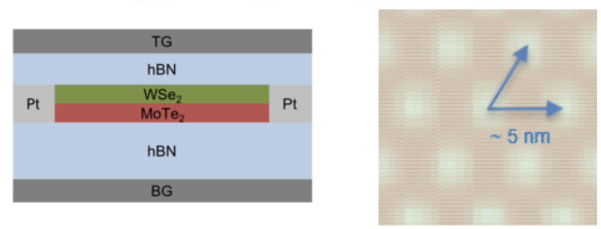


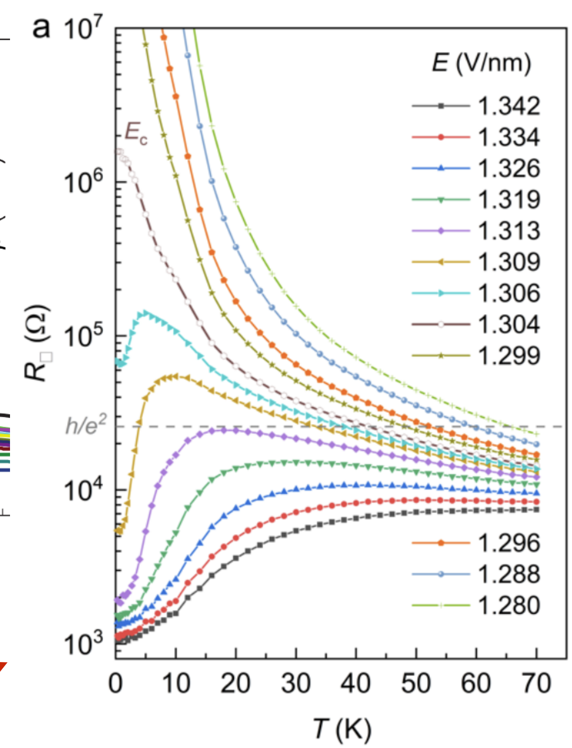
Mott organics (Kanoda, 2005)





Moire TMDs (Shan, Mak, 2021)





Almost the same!

See: Y. Tan, V. D., L. Rademaker, Crystals 2022, 12(7) 932; arXiv:2206.02055

TMD moire bilayers: Mott and beyond!

*- tuning of bandwidth and **band filling** -*

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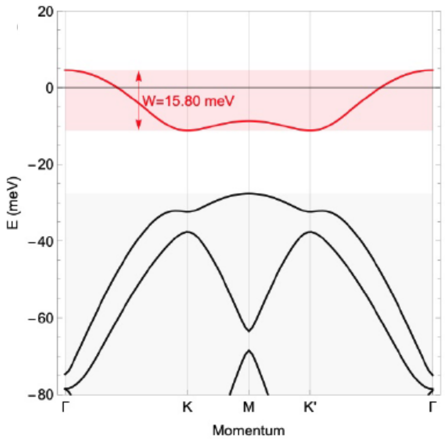
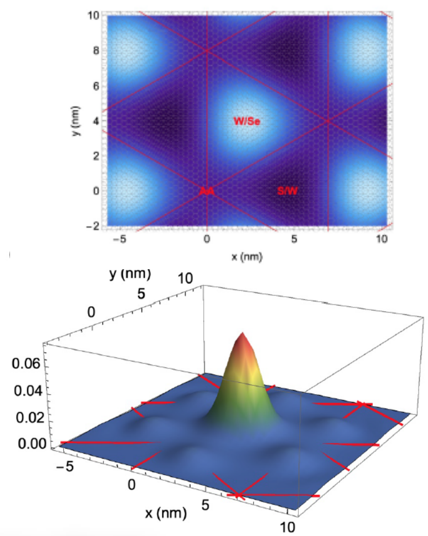
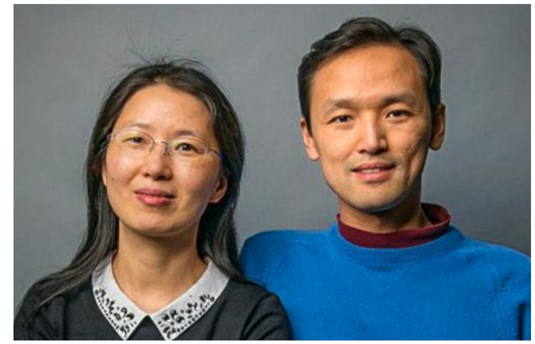
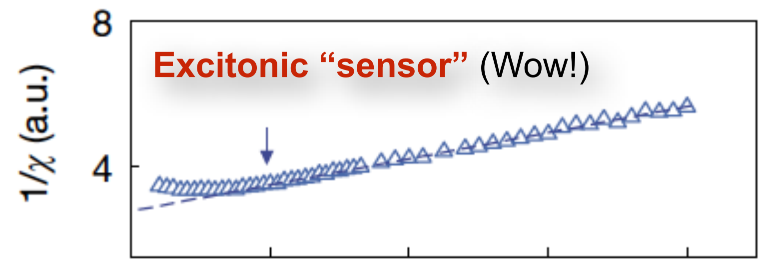




Tuning band width via electric field

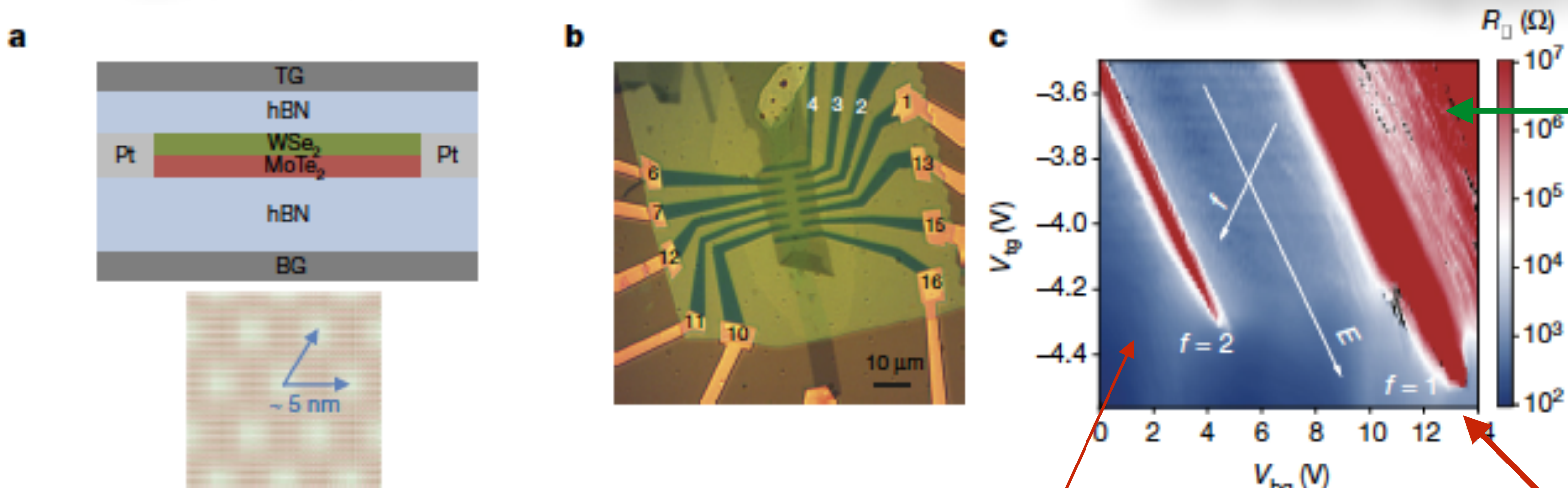


(Shan & Mak, Cornell)



Excitonic "sensor" (Wow!)

Local moment magnetism at f=1 (half filling)



Wigner-Mott?
(0 < f < 1)

Band insulator
(f = 2)

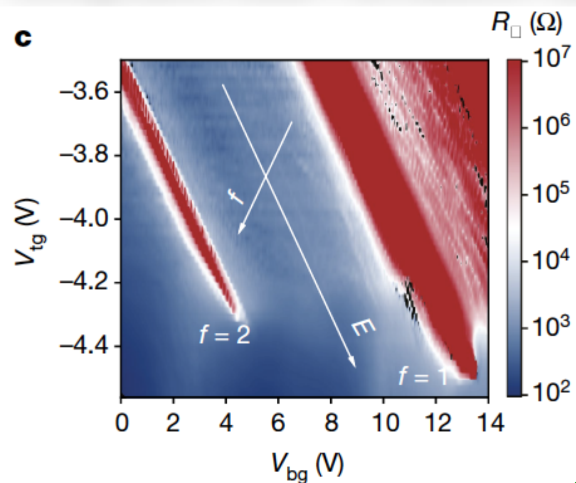
Mott insulator
(f = 1)

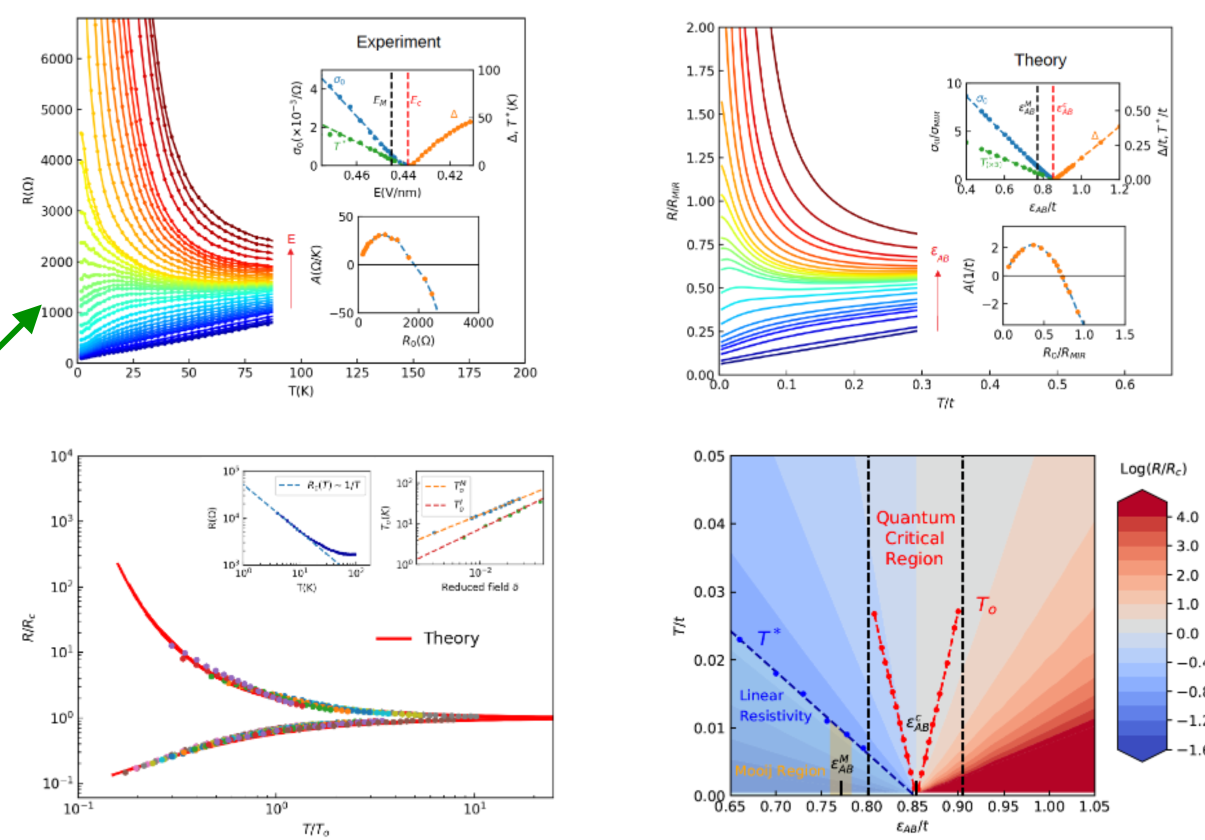
CPA+DMFT theory: quantum critical scaling for disorder-driven MIT in moire devices (f=2)

(arXiv:2112.11522)

Yuting Tan

Tuning band width via electric field at f = 2





Slope A changes sign ("Mooij correlation")

$$\sigma_0 = 1/R_0 \sim (E - E_c)$$

Continious, disorder-dominated MIT!

quantum criticality, scaling!!

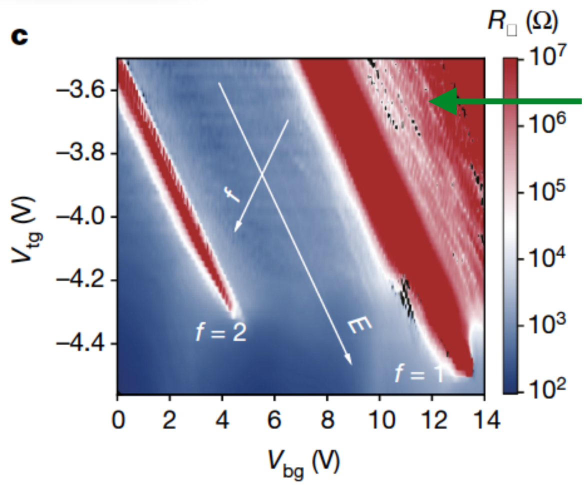
All experimental trends captured by theory!

Louk Rademaker

ECRYS: Mottness beyond half-filling!

(soon on arXiv)

Wigner

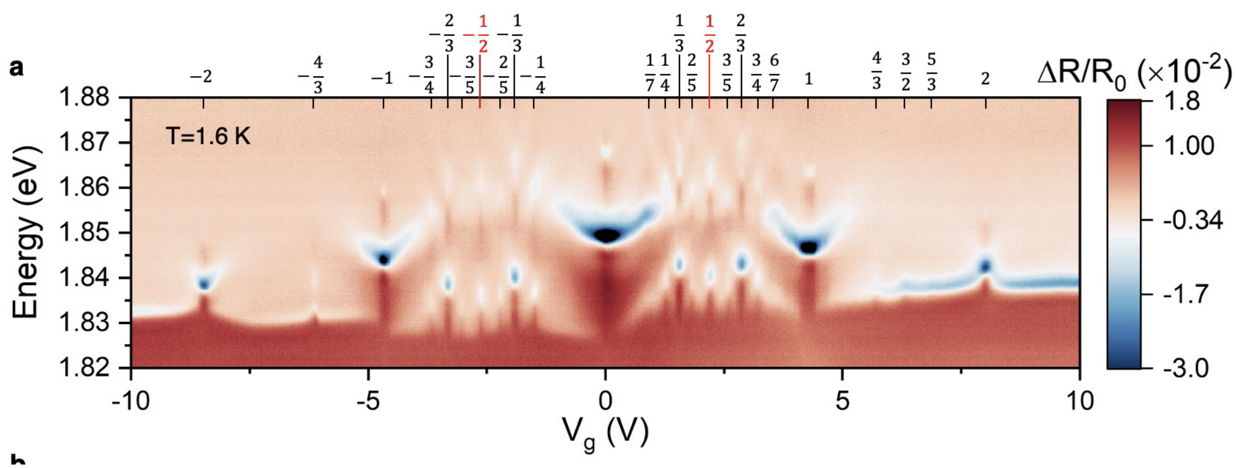


Wigner-Mott?
(0 < f < 1)

Nature Physics **4**, 932 - 935 (2008)

Coulomb correlations and the Wigner–Mott transition

A. Camjayi, K. Haule, V. Dobrosavljevic & G. Kotliar



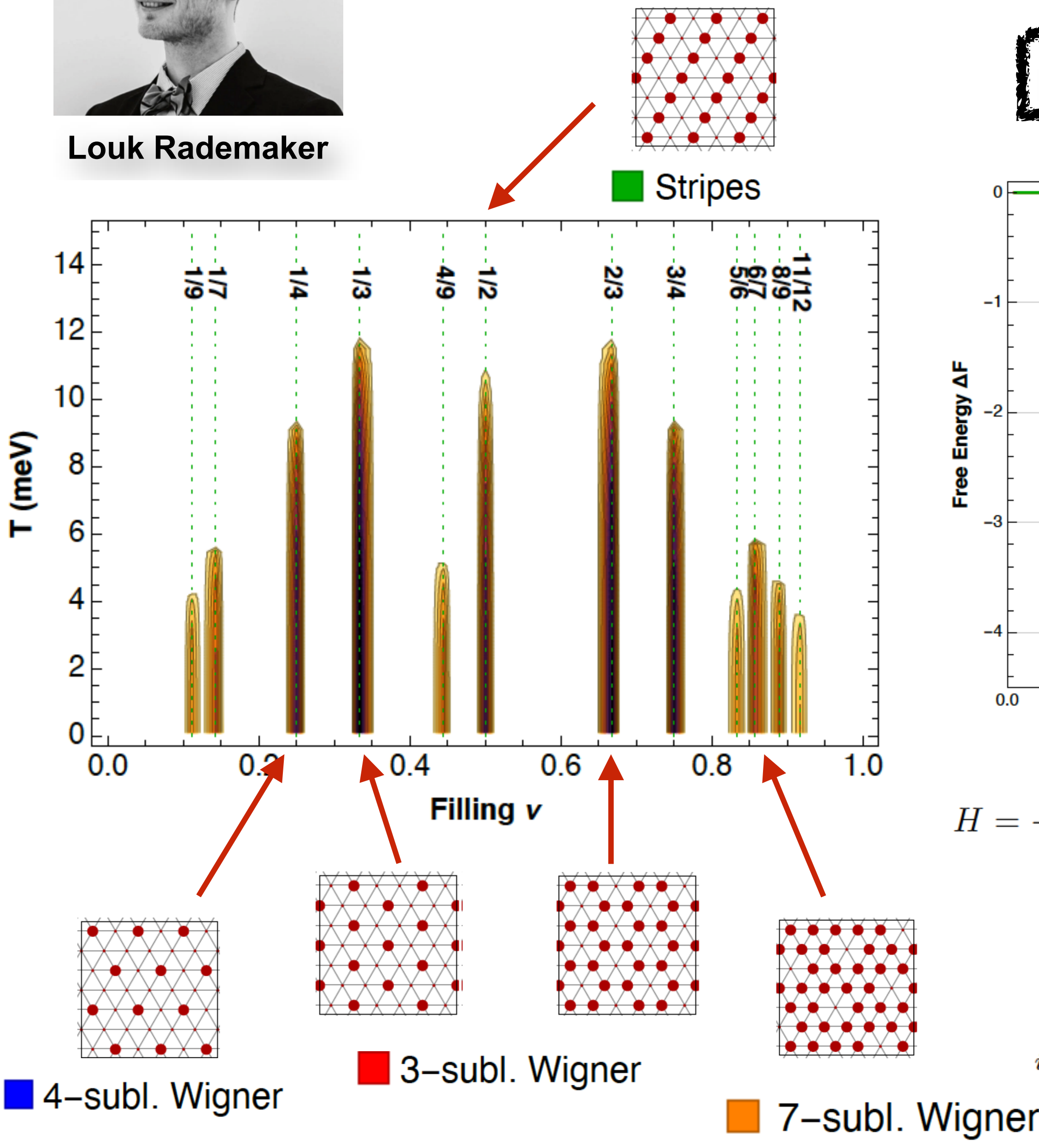
Experiment: Shan & Mak, Nature, 2020, excitonic sensor!!

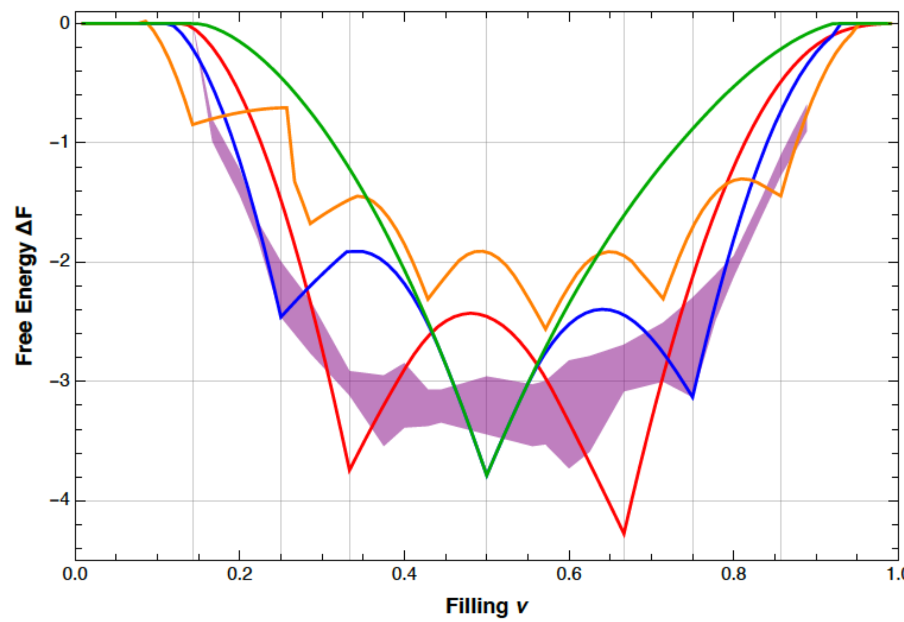
ECRYS: Mottness beyond half-filling!

Louk Rademaker

Wigner

Competing charge orders!!





$$H = -\sum_{ij,\sigma} t_{ij} c^{\dagger}_{i,\sigma} c_{j,\sigma} + \sum_i U n_{i,\uparrow} n_{i,\downarrow} + \sum_{i,j\neq i,\sigma_1,\sigma_2} V_{ij} n_{i,\sigma_1} n_{j,\sigma_2}$$

Charge-order: Hartree theory

$$\sum_{i,j\neq i,\sigma_1,\sigma_2} V_{ij} n_{i,\sigma_1} n_{j,\sigma_2} \rightarrow \sum_{i,\sigma_1} n_{i,\sigma_1} \left(\sum_{j\neq i,\sigma_2} V_{ij} \langle n_j \rangle \right)$$

Effective site energy $\varepsilon_i \equiv \sum_{j\neq i,\sigma_2} V_{ij} \langle n_j \rangle$

ECRYS: Mottness beyond half-filling!

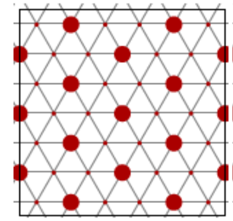
Yuting Tan

Wigner

Effective site energy

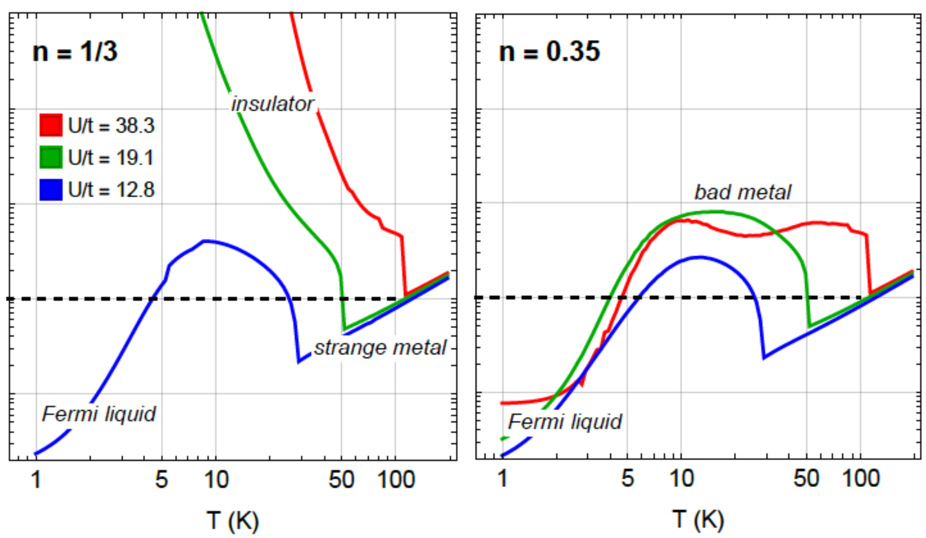
$$\varepsilon_i \equiv \sum_{j\neq i,\sigma_2} V_{ij} \langle n_j \rangle$$

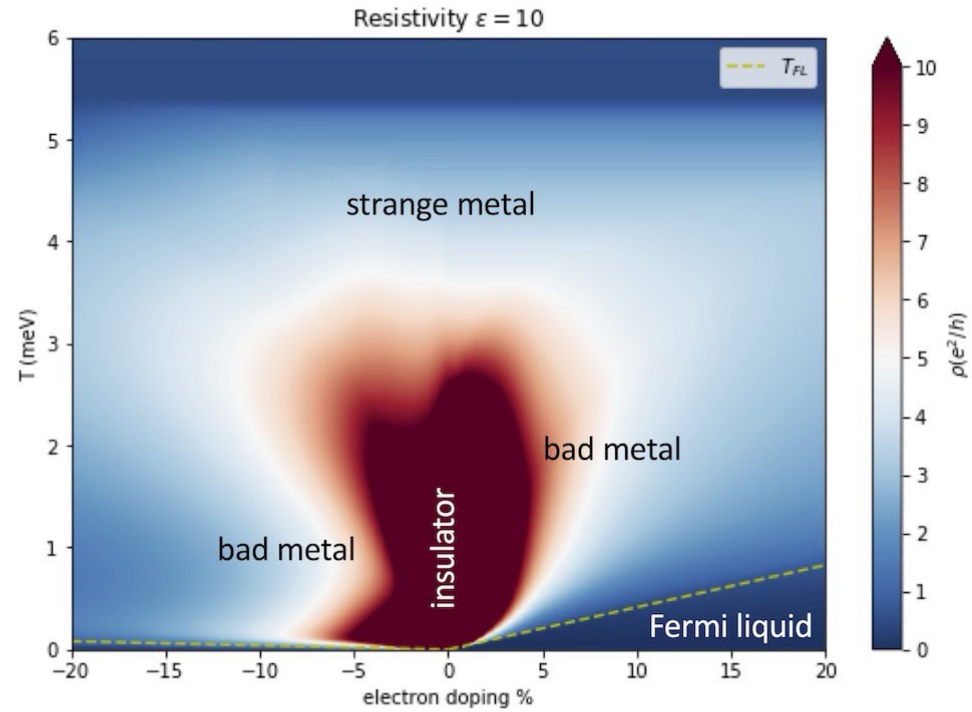
$$H_{\mathrm{eff}} = -\sum_{ij,\sigma} t_{ij} c^{\dagger}_{i,\sigma} c_{j,\sigma} + \sum_{i,\sigma} n_{i,\sigma}\varepsilon_i + \sum_i U n_{i,\uparrow} n_{i,\downarrow}.$$



3–subl. Wigner

Onsite Coulomb correlations, transport: DMFT



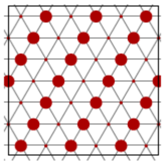


Quantum effects: particle-hole asymmetry

ECRYS+: self-generated Wigner-Mott glasses!

Louk Rademaker

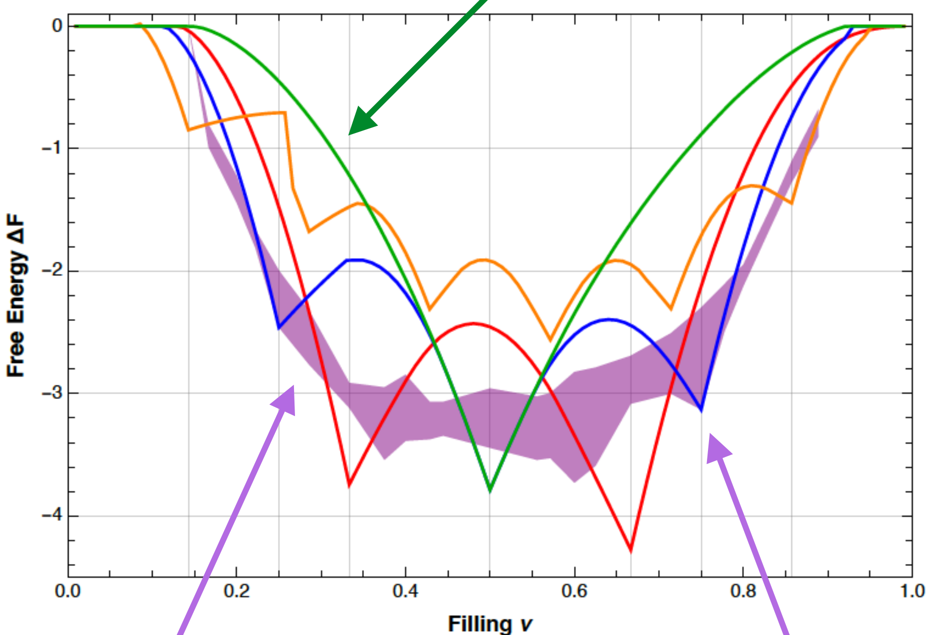
Stripes

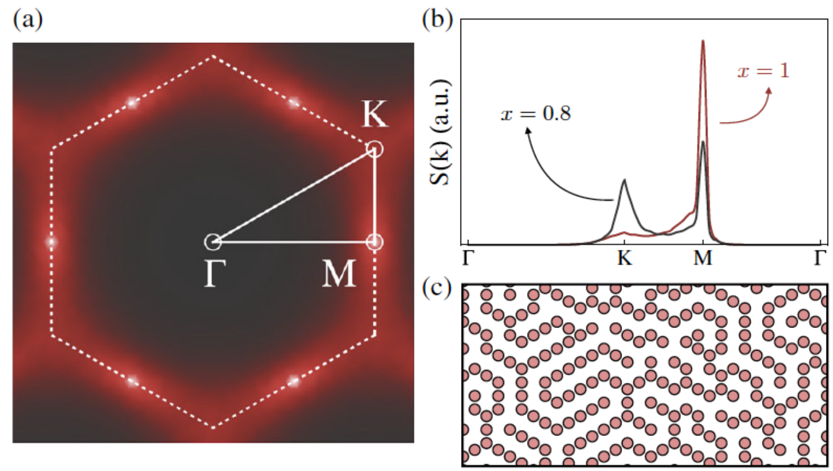


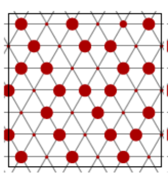
PRL 115, 025701 (2015) PHYSICAL REVIEW LETTERS week ending 10 JULY 2015

Glassy Dynamics in Geometrically Frustrated Coulomb Liquids without Disorder

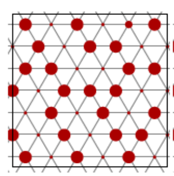
Samiyeh Mahmoudian,[1] Louk Rademaker,[2] Arnaud Ralko,[3] Simone Fratini,[3] and Vladimir Dobrosavljević[1]





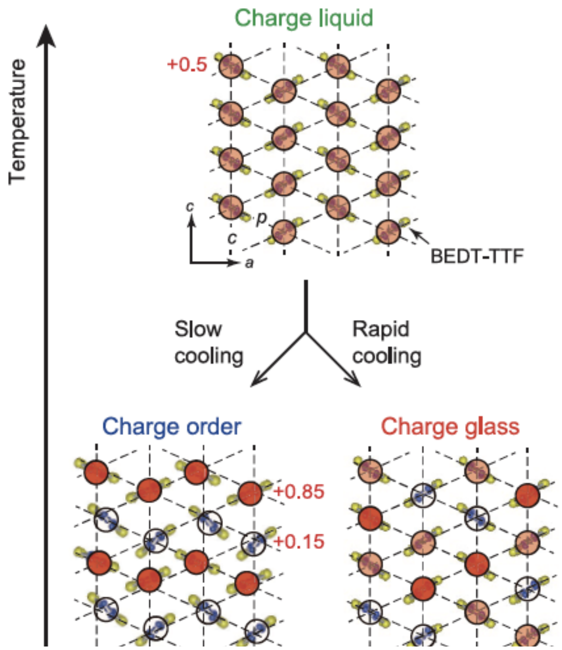


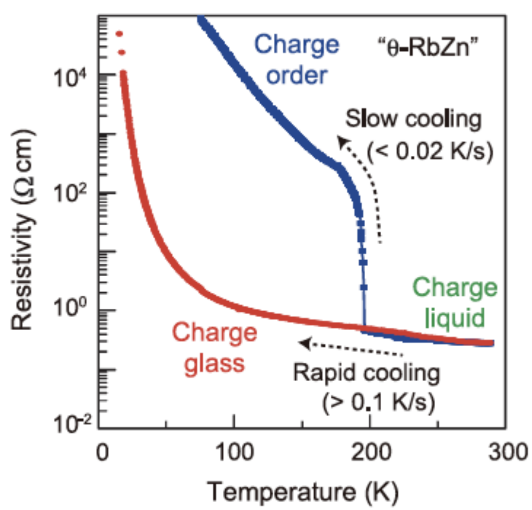
Amorphous states



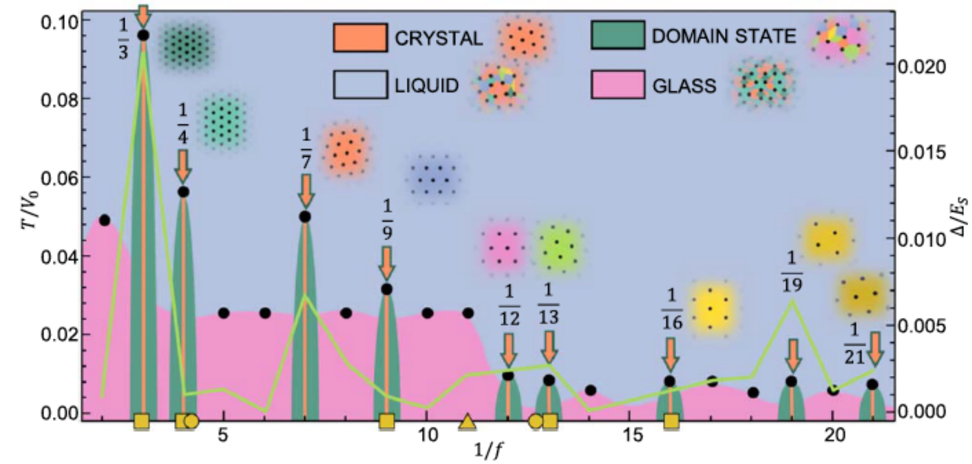
Competing charge orders - glassiness?

How common are Wigner-Mott glasses?



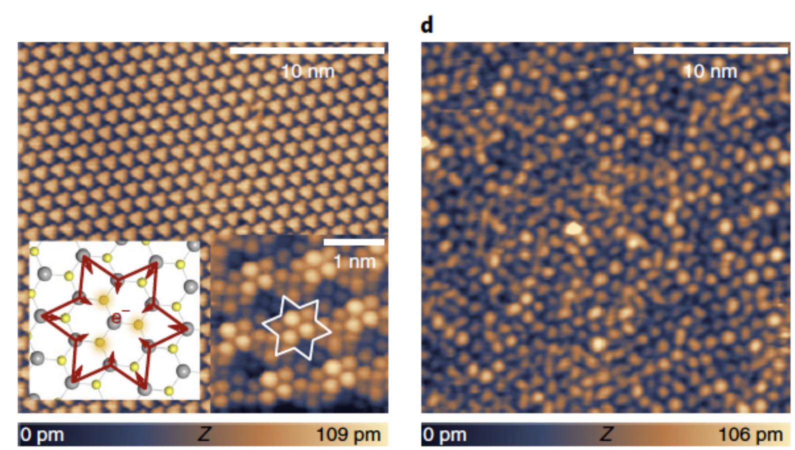


P. Monceau, K. Kanoda,…



System	f	Phase
2H-$Fe_{0.33}TaS_2$ [105]	1/3	Crystal
1T-$TiSe_2$	1/4	Crystal
N_2H_4/1T-TaS_2 [58]	1/4	Crystal
N_2H_4/2H-TaS_2 [58]	1/4	Crystal
1T-$Cu_{0.08}TiSe_2$ [54]	1/4.2	Domain state
2H-$Fe_{0.33}TaSe_2$ [105]	1/4	Crystal
2H-$Fe_{0.33}NbSe_2$ [105]	1/4	Crystal
Alkali/1T-TaS_2 [56, 57]	∼1/8	Glass
N_2H_4/1T-TaS_2 [58]	∼1/8	Glass
2H-TaS_2 [106]	1/9	Crystal
2H-$TaSe_2$ [106]	1/9	Crystal
2H-$NbSe_2$ [59]	∼1/9	Domain state
Cu/1T-TaS_2 [107]	1/9	Crystal
Alkali/1T-TaS_2 [108]	1/9	Crystal
N_2H_4/1T-TaS_2 [58]	1/9	Crystal
PD 1T-TaS_2	1/11	Glass
1T-$Nb_{0.1}TaS_2$ [51]	∼1/11	Possible glass
PD 1T-TaS_2	1/12.6	Domain state
1T-TaSeS	1/12.6	Domain state
1T-$Ta_{0.99}Fe_{0.01}S_2$	1/12.6	Domain state
1T-$Ti_{0.07}Ta_{0.93}Se_2$ [52]	1/12.6	Domain state
1T-$Nb_{0.04}TaS_2$ [51]	∼1/13	Domain state
1T-$Nb_{0.07}TaS_2$ [51]	∼1/13	Domain state
1T-TaS_2	1/13	Crystal
4Hb-TaS_2 [106]	1/13	Crystal
1T-$TaSe_2$	1/13	Crystal
4Hb-$TaSe_2$ [106]	1/13	Crystal
1T-$NbSe_2$ [106]	1/13	Crystal
1T-VSe_2 [106]	1/16	Crystal

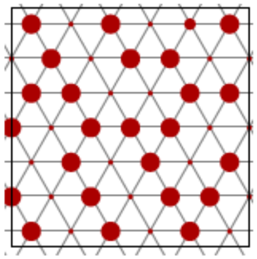
1T-TaS_2

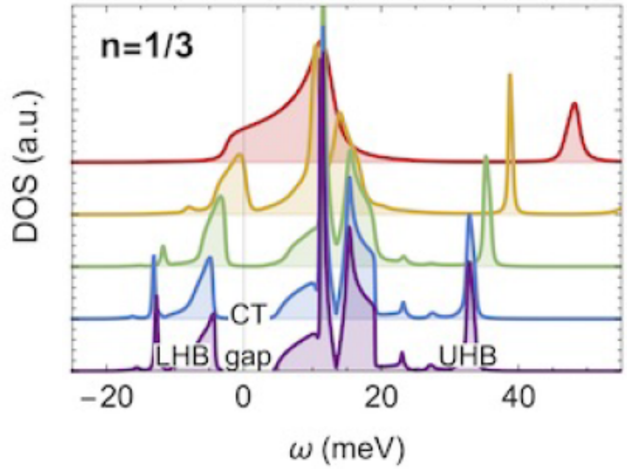


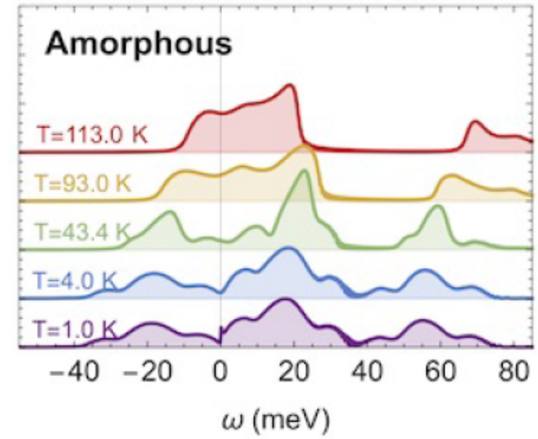
D. Mihailovic et al.

"Electron slush": transport in Wigner-Mott glasses!

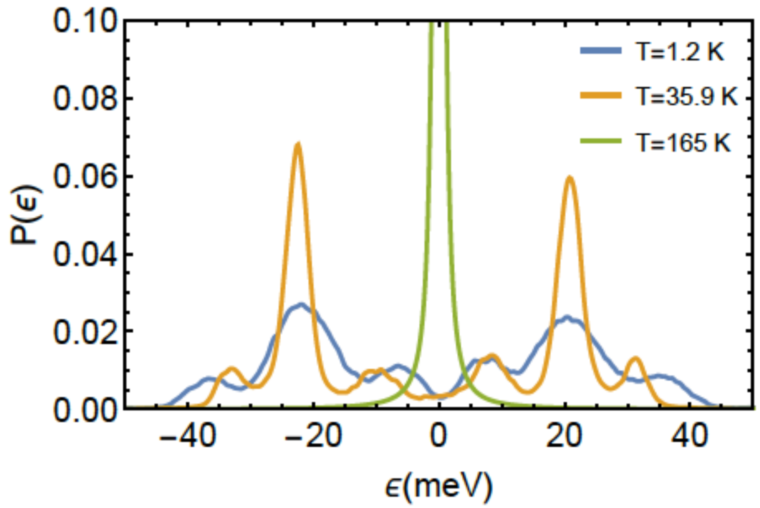
Yuting Tan



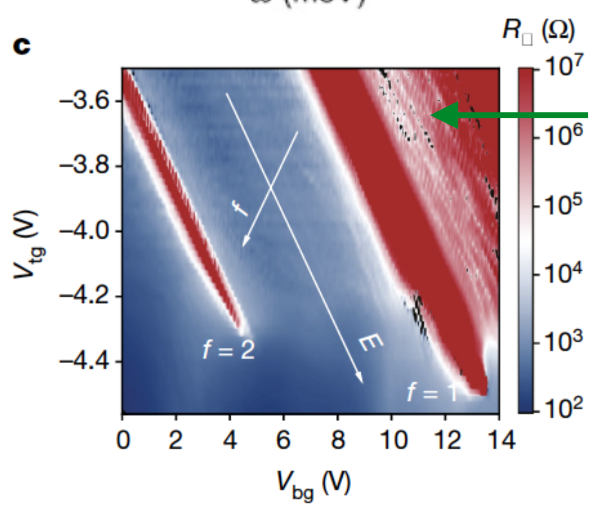




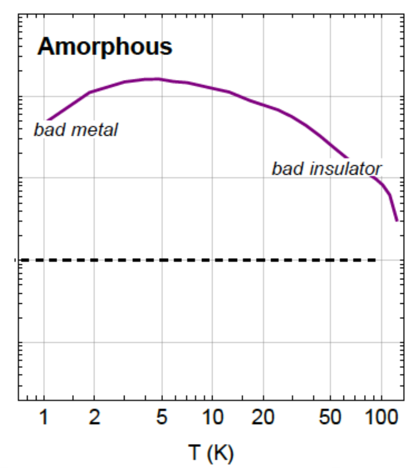
Effective site energy $\varepsilon_i \equiv \sum_{j \neq i, \sigma_2} V_{ij} \langle n_j \rangle$



Histogram for amorphous state at $T = 1.2K, 35.9K, 165K$.



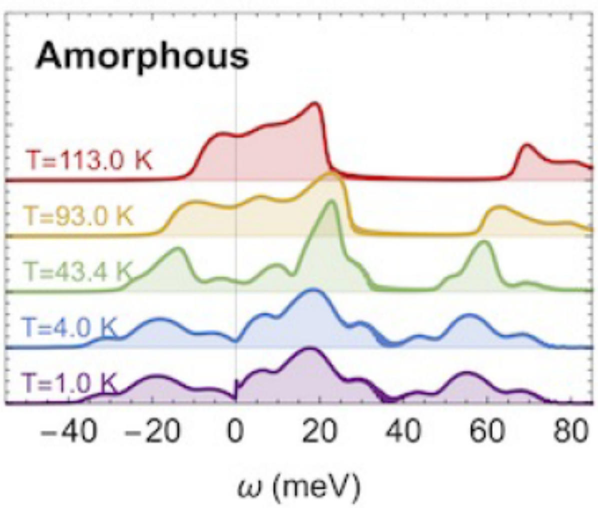
Wigner-Mott?
(0 < f < 1)



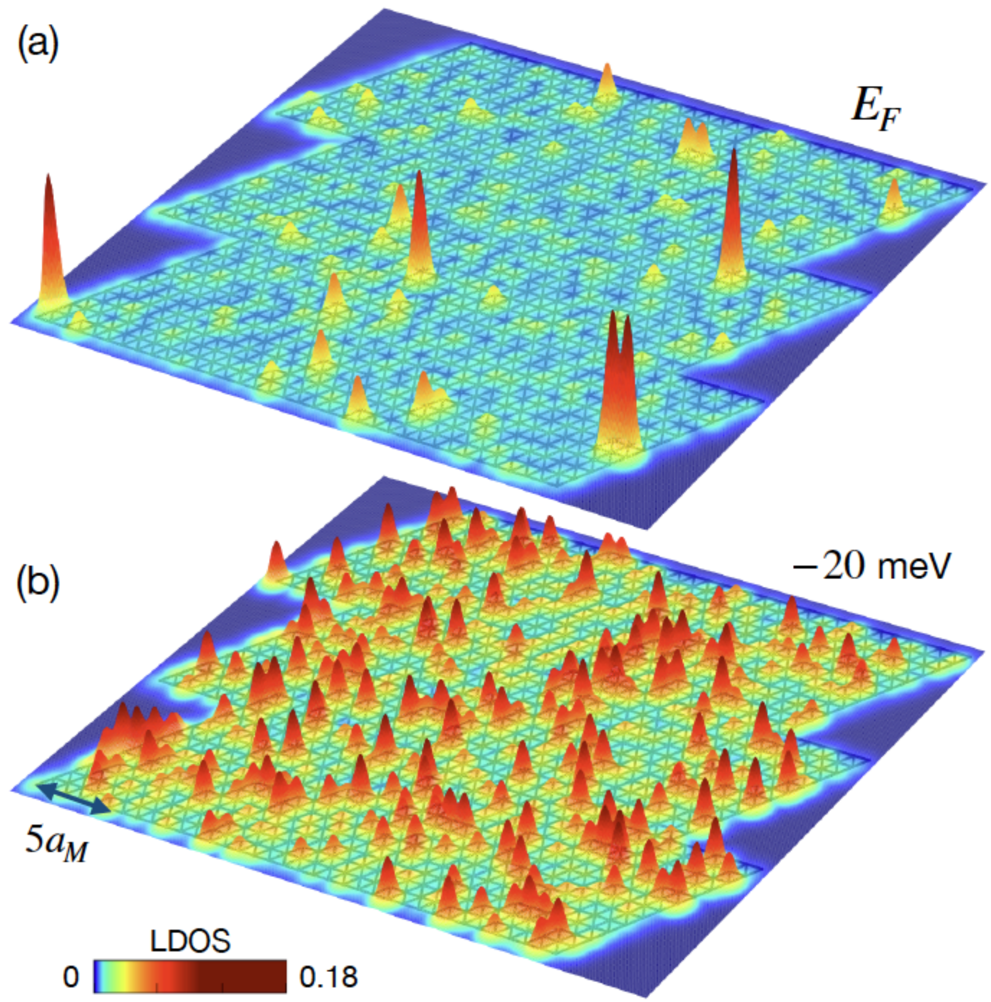
"Pseudogap transport": weakly insulating?

“Electron slush”: STM signatures?

Yuting Tan



Amorphous electronic states depleted near the Fermi energy




Yuting Tan

Perspectives and challenges


Louk Rademaker

- TMD Moire bilayers as ideal realizations of many MIT universality classes
- Mott, Wigner-Mott, and disorder-driven transitions + more…
- DMFT describes suprisingly well not only Mott but also disorder-driven MIT

- Open questions:

  A. Can onset of charge order be separated from MIT (probably yes)?

  B. Wigner-Mott crystal vs. Wigner-Mott glass MITs? Polarons, localization?

  C. Glassy and other non-equilibrium effects (weak thermalization, MBL)?