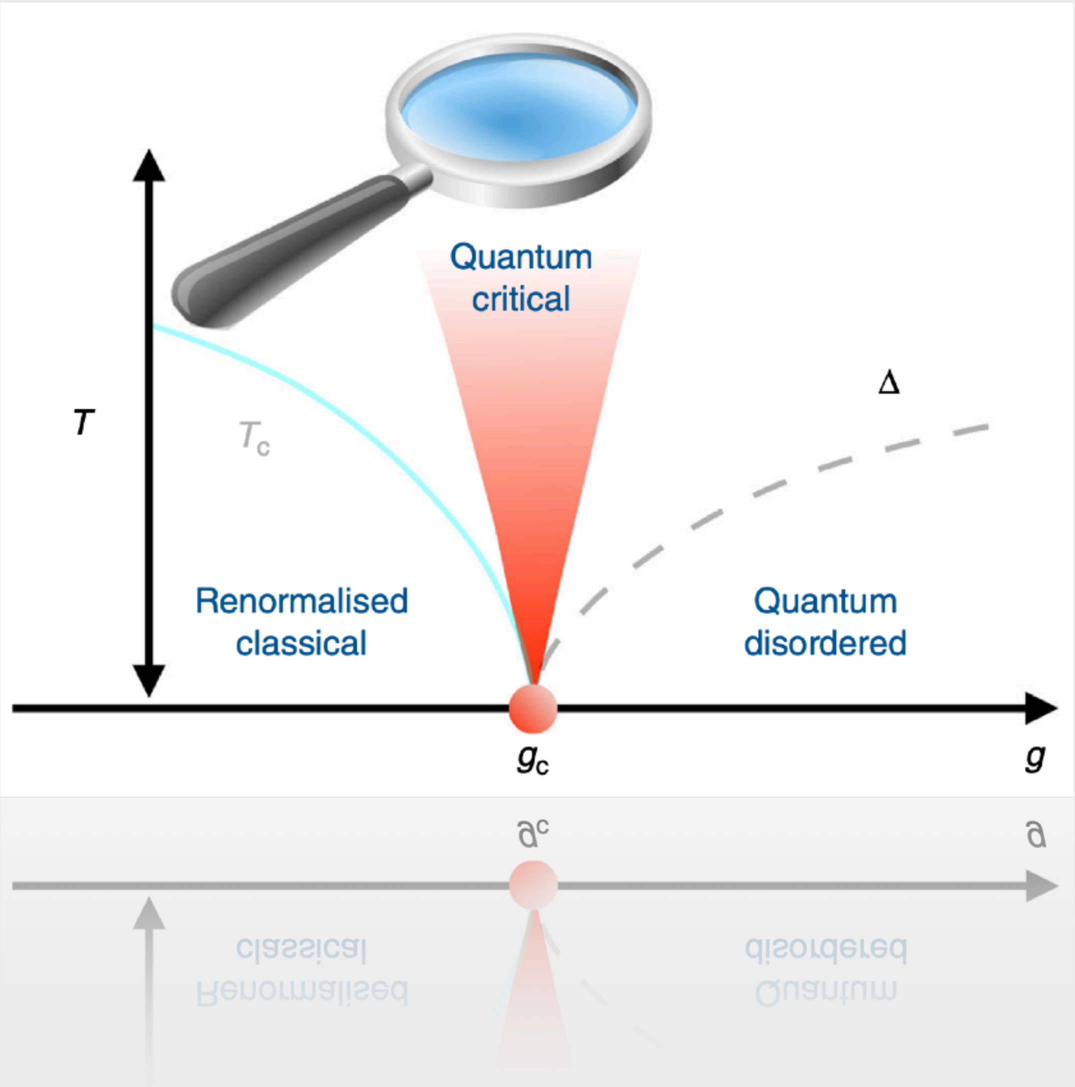
Many-body correlations and entanglement?

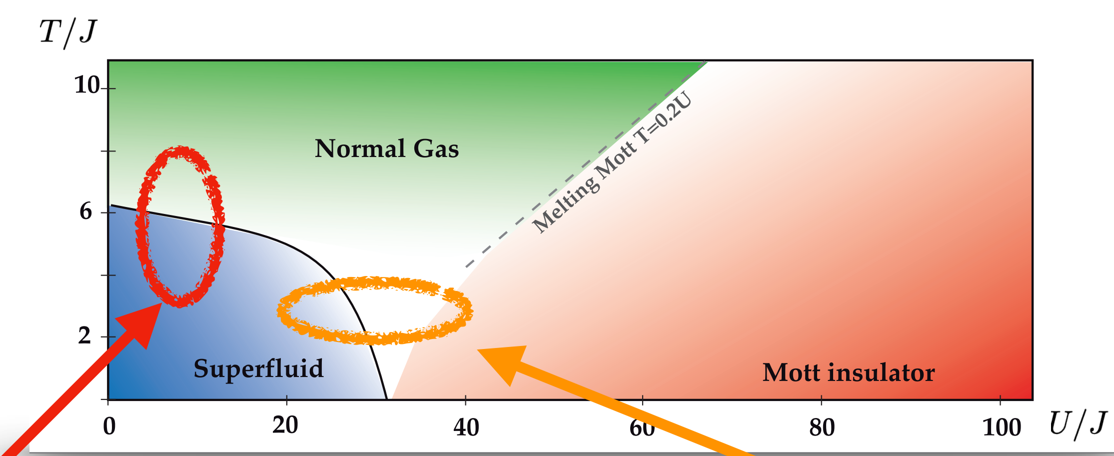


Reconstructing the quantum critical fan of strongly correlated systems using quantum correlations

Irénée Frérot & Tommaso Roscilde

Nature Communications **10**, Article number: 577 (2019) | Cite this article

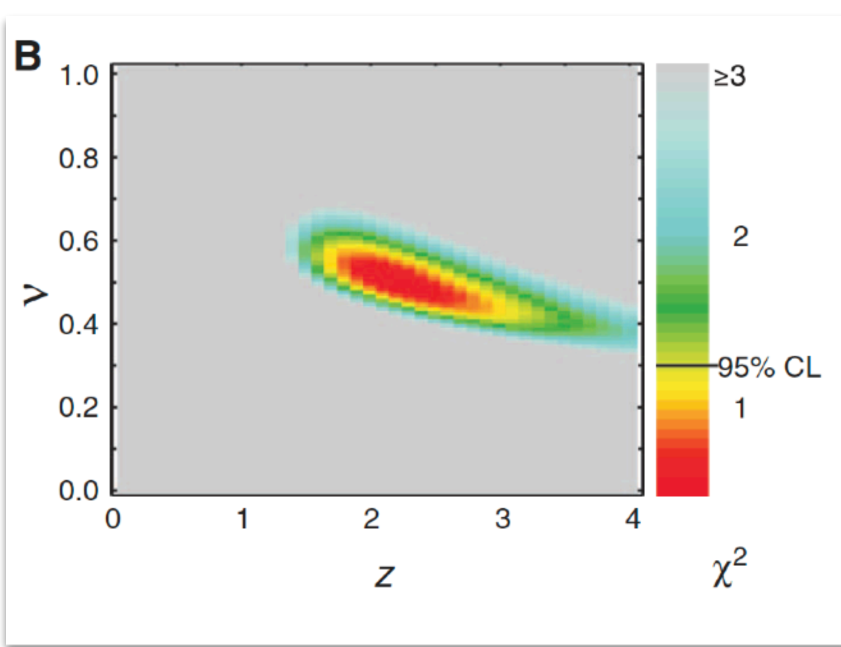
Critical exponents?



Normal-superfluid phase transition in a 2D lattice Bose gas

$$\frac{k_B T_c}{t} = c\left(\frac{\mu - \mu_0}{t}\right)^{z\nu}$$

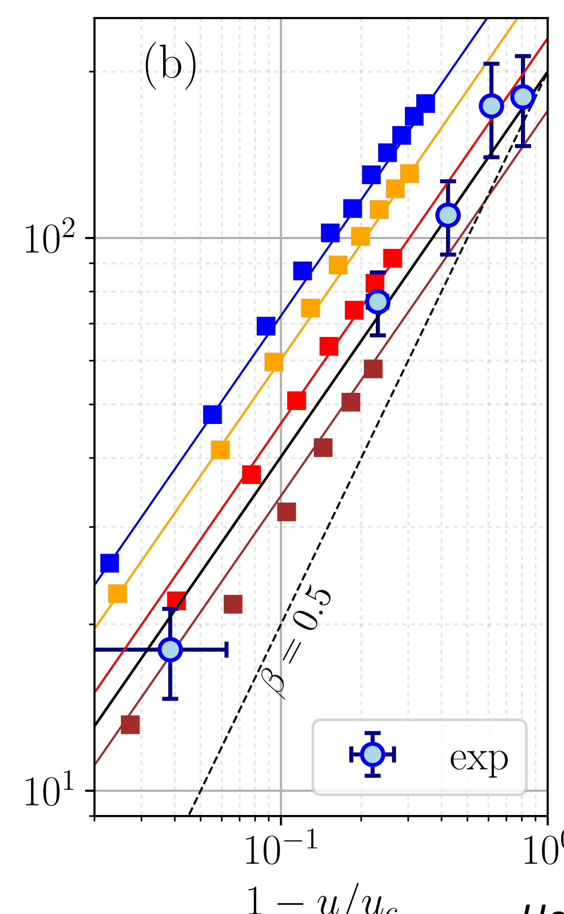
$$z = 2$$
$$\nu = 0.5$$



Zhang et al. Science ***335****, 1070 (2012)*

Mott crossover in 3D lattice

$$\rho_0(u) = \rho_0^{u=0}|1 - u/u_c|^{2\beta}$$

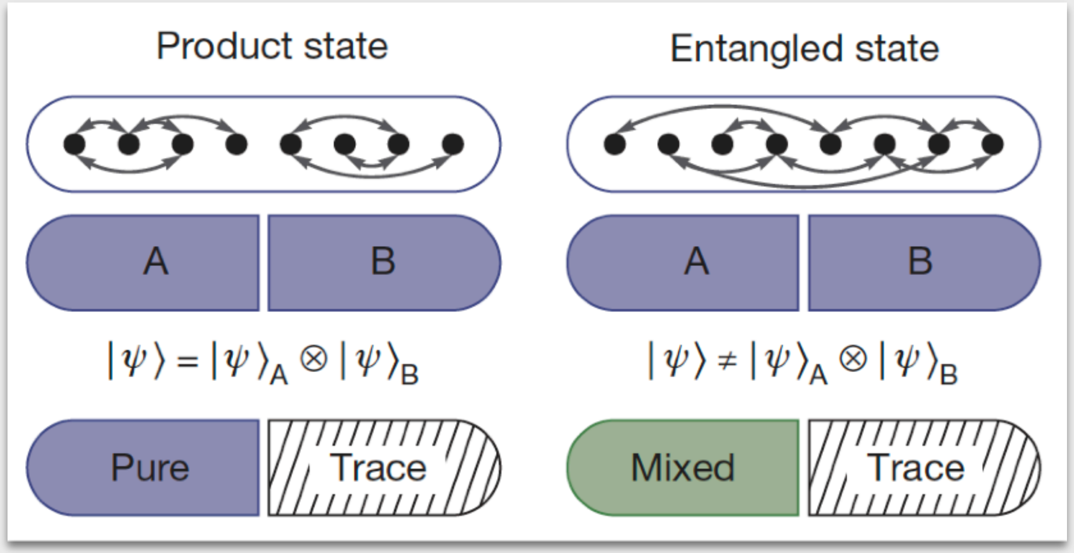


3D XY class: $\beta = 0.3485$

Mean-field: $\beta = 0.5$

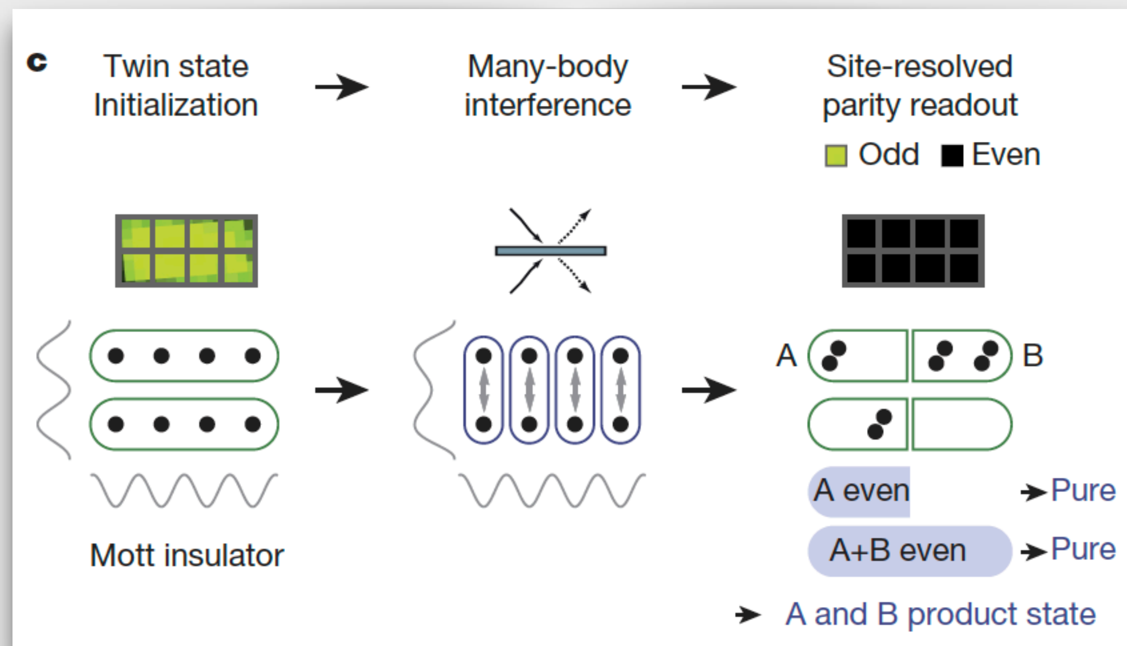
Hercé et al. Phys. Rev. A ***104****, L011301 (2021)*

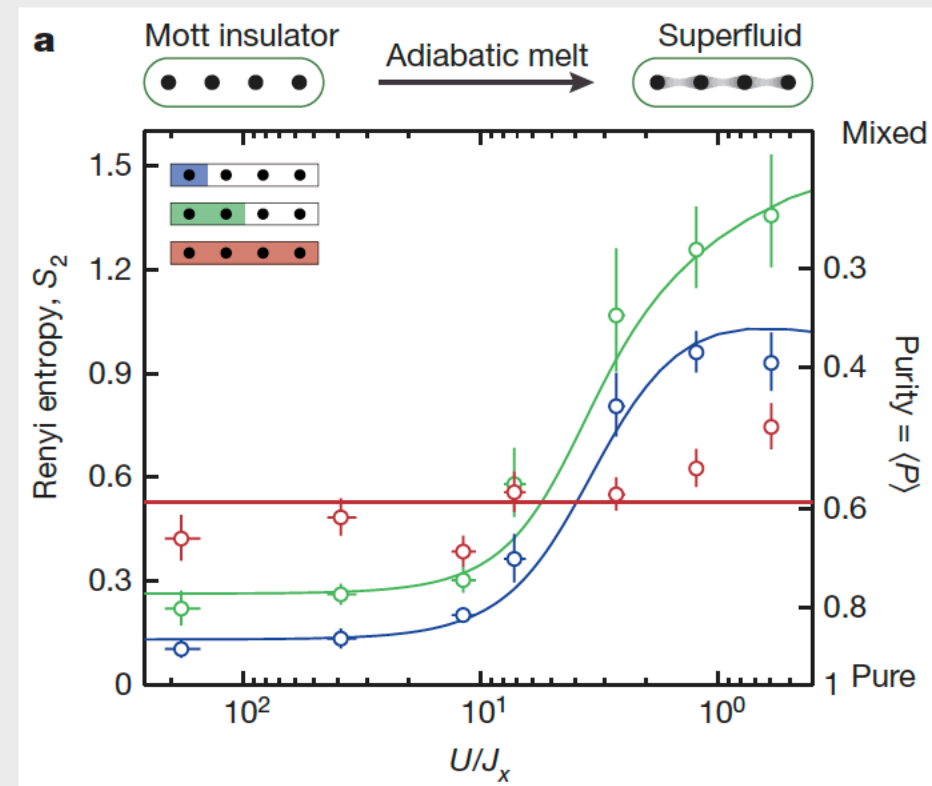
Many-body correlations and entanglement?



n-order Renyi entropy:

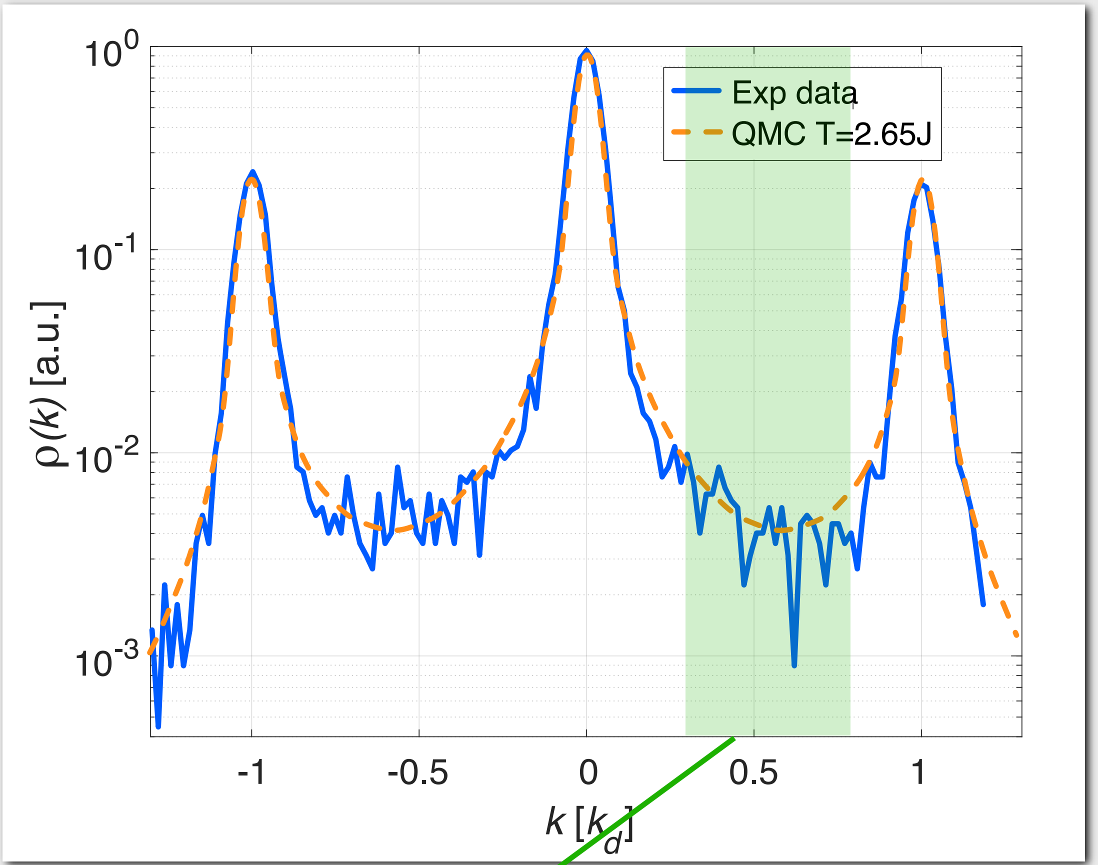
$$S_n(\mathrm{A}) = \frac{1}{1-n} \log \mathrm{Tr}(\rho_{\mathrm{A}}^n)$$

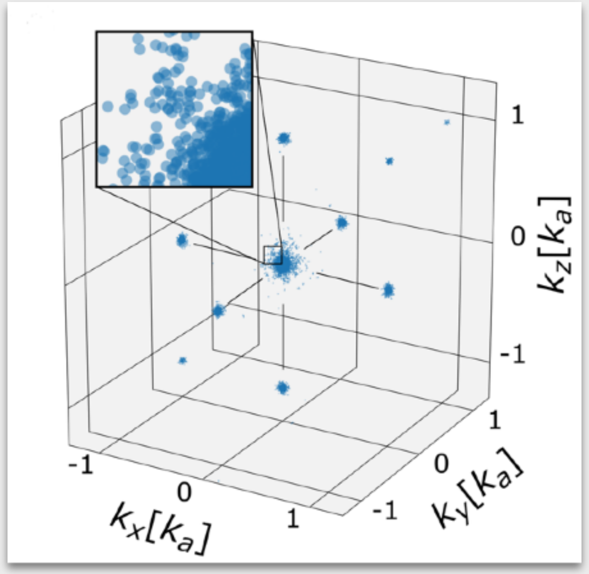




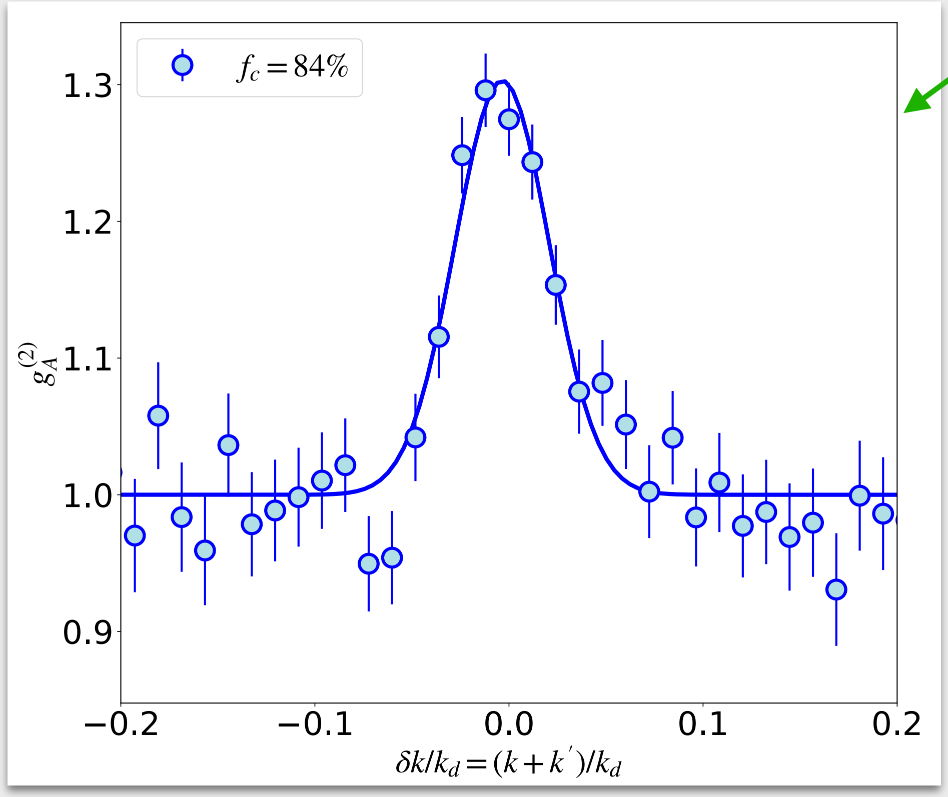
Islam et al. Nature ***528****, 77 (2015)*

Atom pairs in the quantum depletion





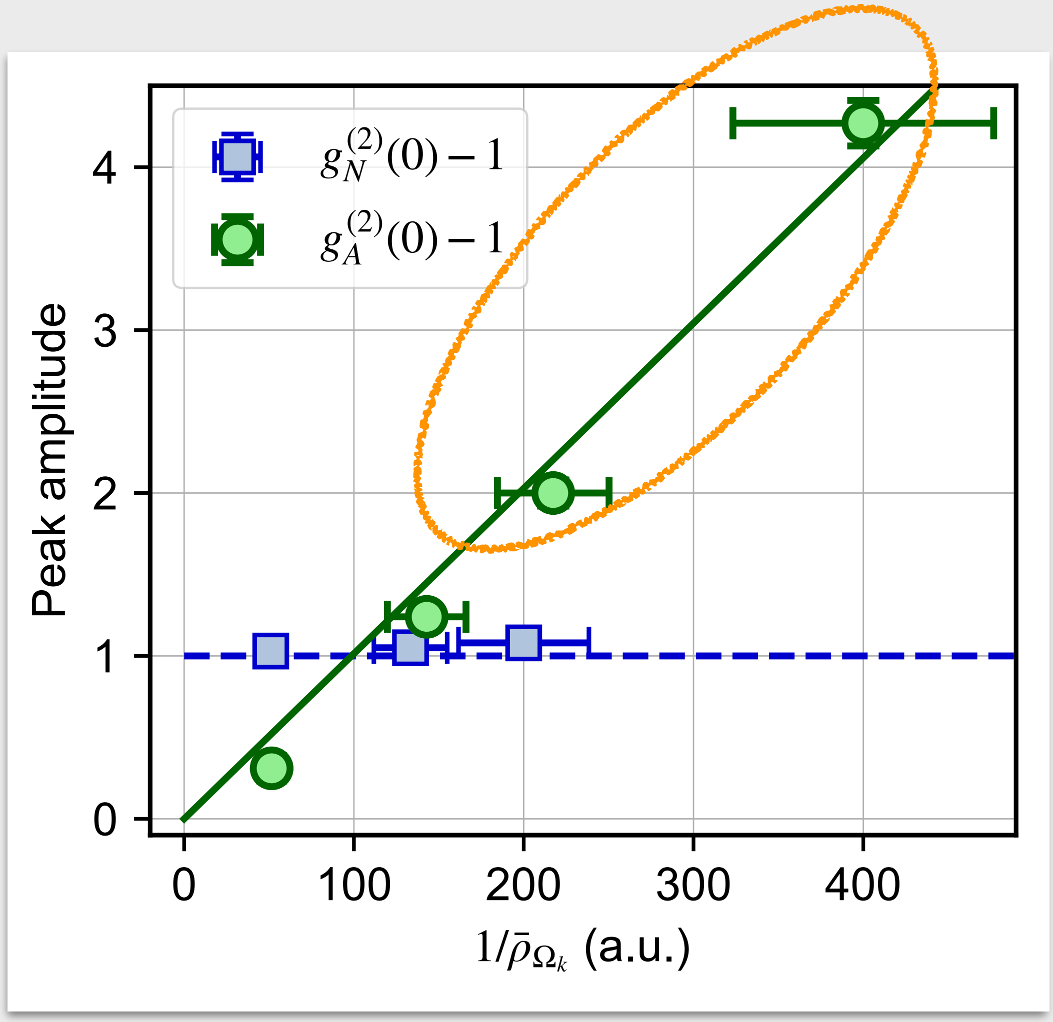
Anomalous correlations



Observation of atom pairs at opposite momenta in the depletion of an interacting Bose gas: **microscopic mechanism for the quantum depletion in Bogoliubov theory**

Tenart et al. arxiv:2105.05664 (2021)

Atom pairs in the quantum depletion



Tenart et al. arxiv:2105.05664 (2021)

Cauchy-Schwartz inequality :

$$\langle I_1 I_2\rangle \leq \sqrt{\langle I_1^2\rangle\langle I_2^2\rangle} \longrightarrow g_A^{(2)}(0) \leq g_N^{(2)}(0)$$

Violation of CS inequality with a continuous variable (momentum): non-classical correlations

VOLUME 84, NUMBER 12 PHYSICAL REVIEW LETTERS 20 MARCH 2000

Inseparability Criterion for Continuous Variable Systems

Lu-Ming Duan,[1,2,*] G. Giedke,[1] J. I. Cirac,[1] and P. Zoller[1]

PHYSICAL REVIEW D **89,** 105024 (2014)

Quantum entanglement in analogue Hawking radiation: When is the final state nonseparable?

Xavier Busch[*] and Renaud Parentani[†]

Experimental proof of entanglement can be obtained from measuring $\langle a^\dagger(-\mathbf{k})a(\mathbf{k})\rangle \simeq 0$

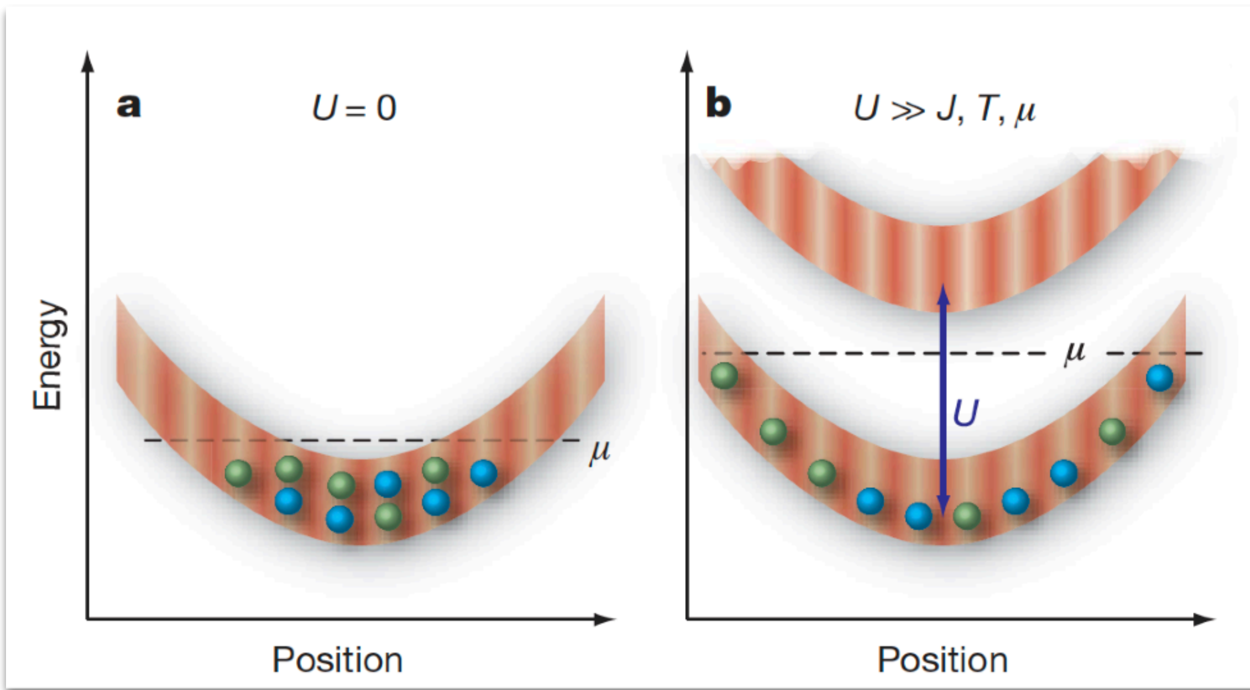
(this term is null in Bogoliubov theory)

Quantum gases in Optical Lattices
Lecture #4

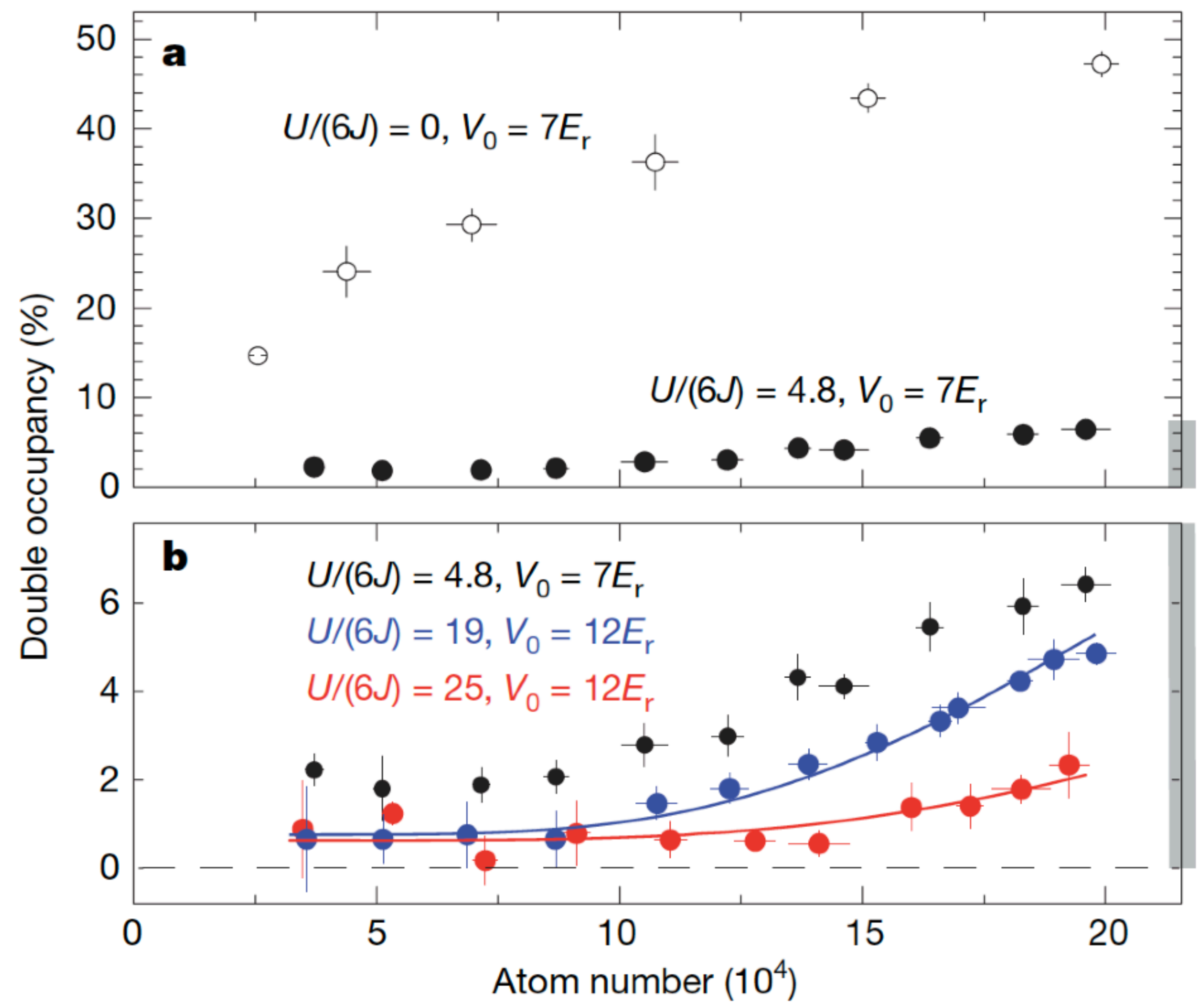
David CLEMENT

Institut d'Optique - Palaiseau, France

Fermionic Mott insulator



Observation of suppression of double occupied sites

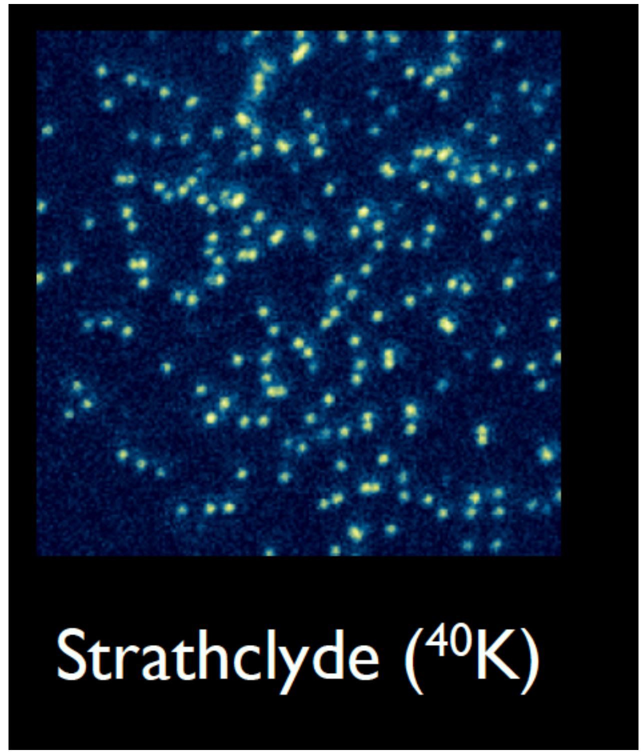


Jordens et al. Nature ***455****, 204 (2008)*

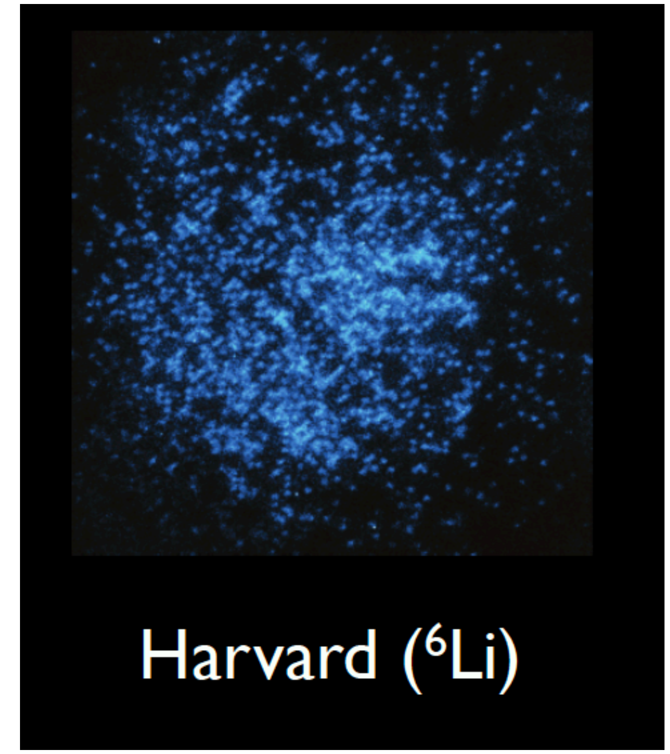
Schneider et al. Science ***322****, 1520 (2008)*

Quantum gas microscopes for fermions

2015 annus mirabilis!

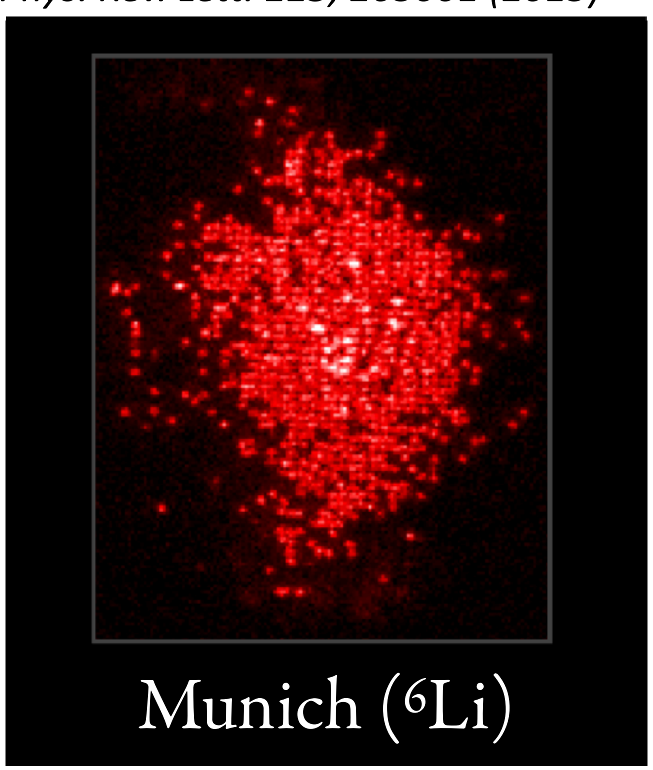


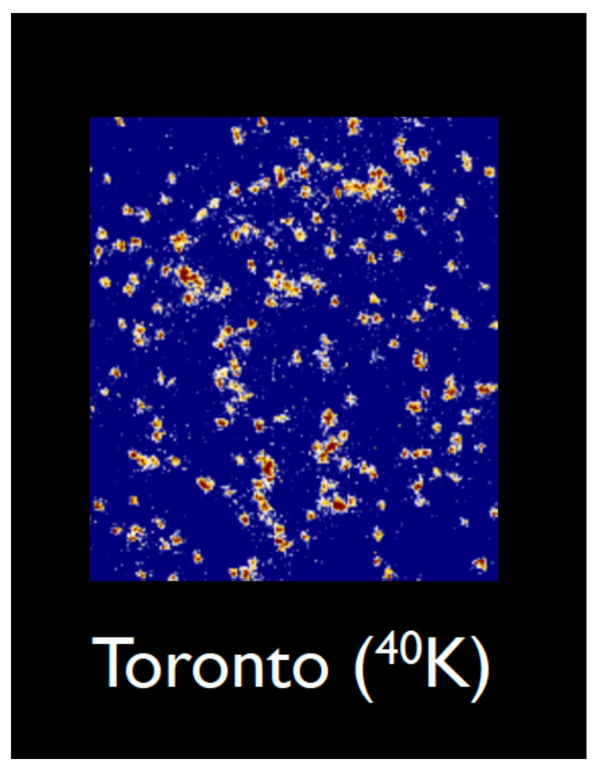
Nat. Phys. ***11****, 738 (2015)*



Phys. Rev. Lett. ***114****, 213002 (2015)*

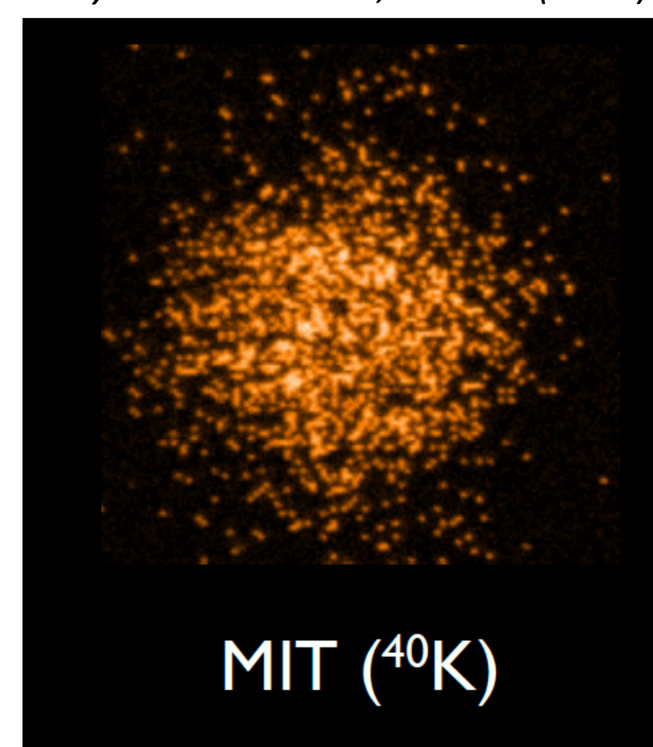
Phys. Rev. Lett. ***115****, 263001 (2015)*



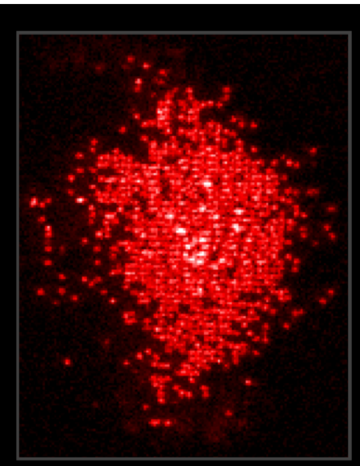


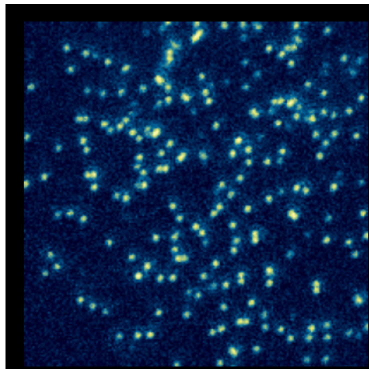
Phys. Rev. A ***92****, 063406 (2015)*

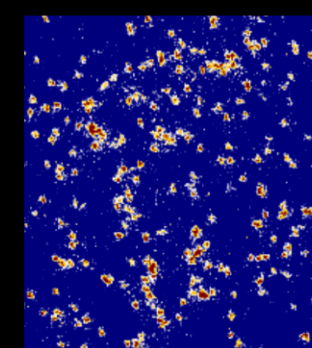
Phys. Rev. Lett. ***114****, 193001 (2015)*

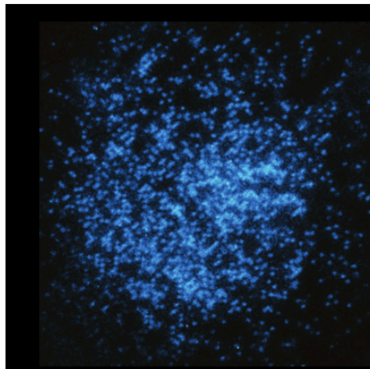


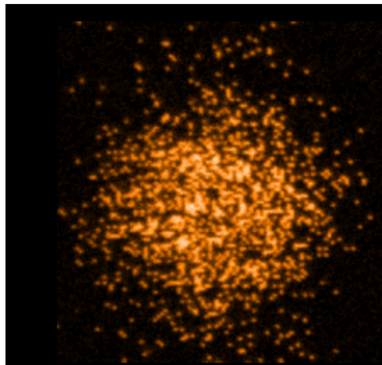
Quantum gas microscopes for fermions

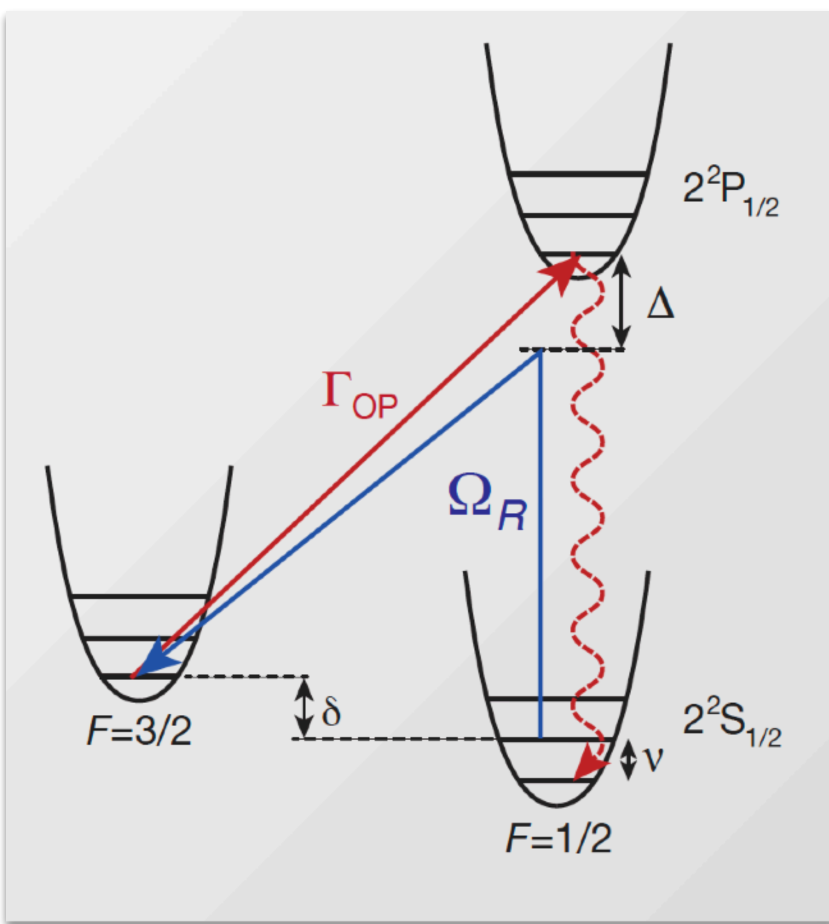

Munich (^{6}Li)


Strathclyde (^{40}K)

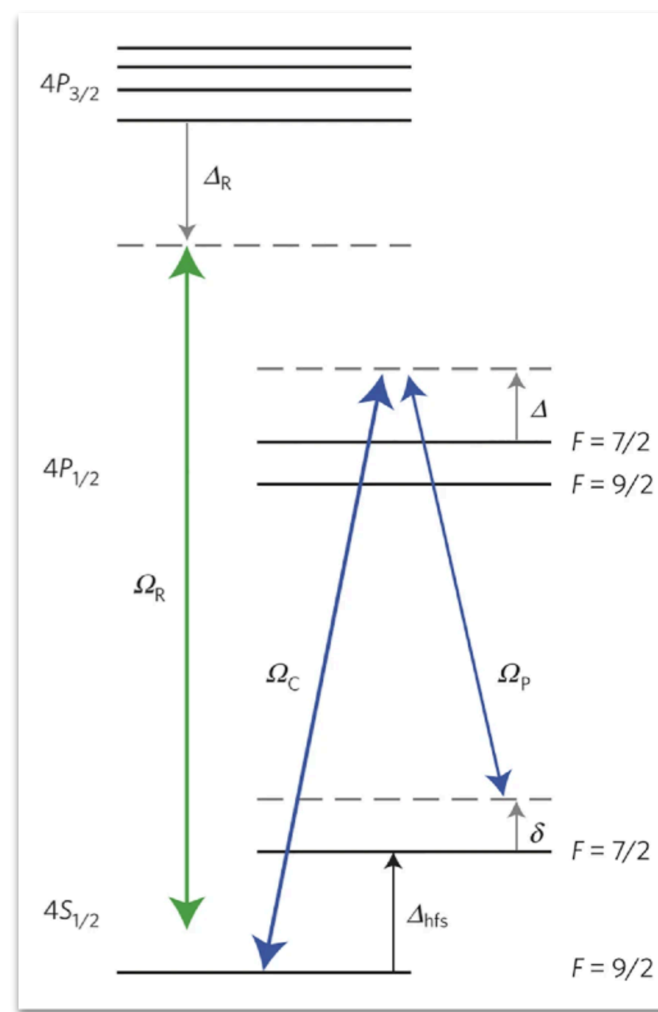

Toronto (^{40}K)


Harvard (^{6}Li)


MIT (^{40}K)

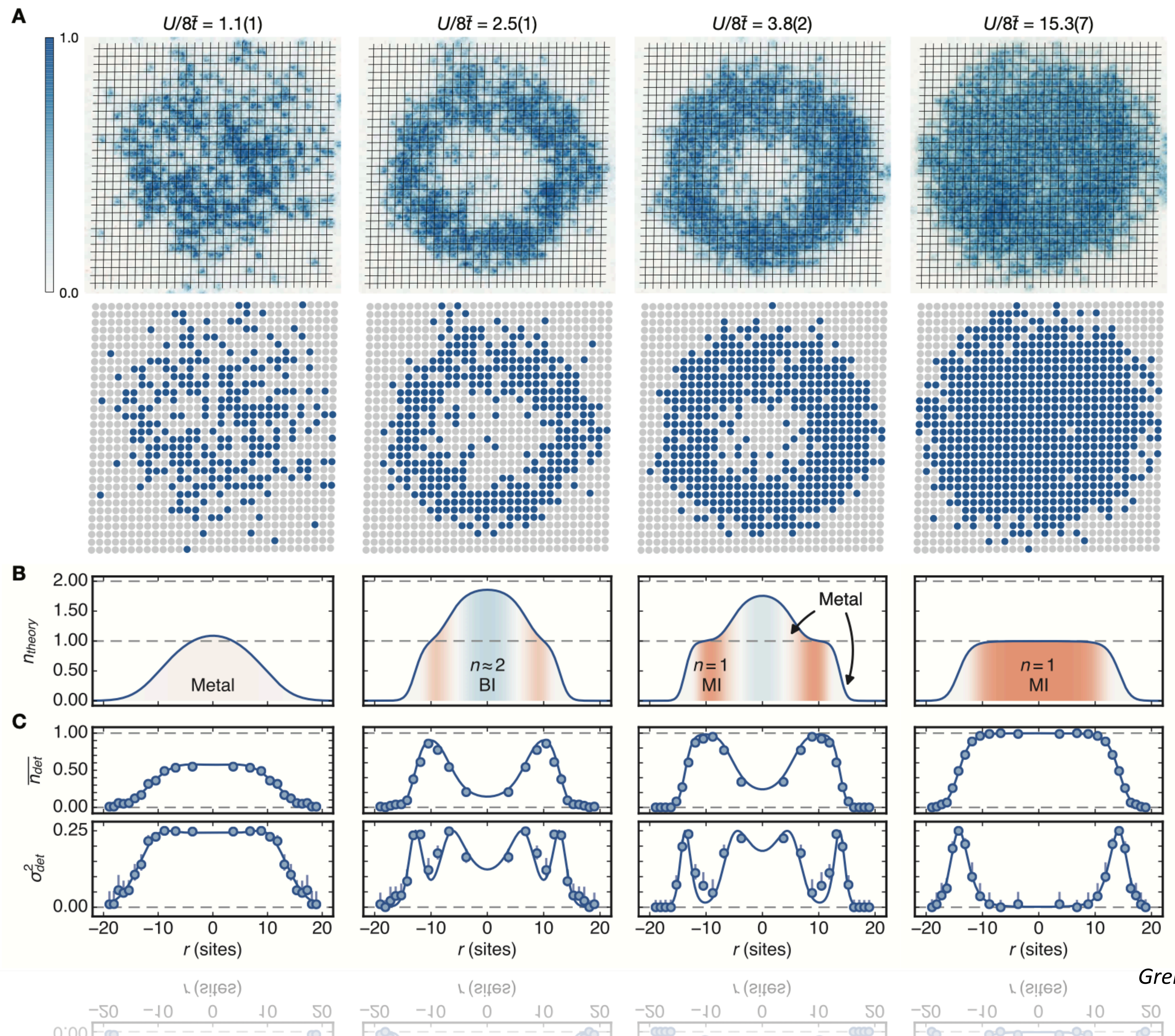


Raman sideband cooling



EIT cooling

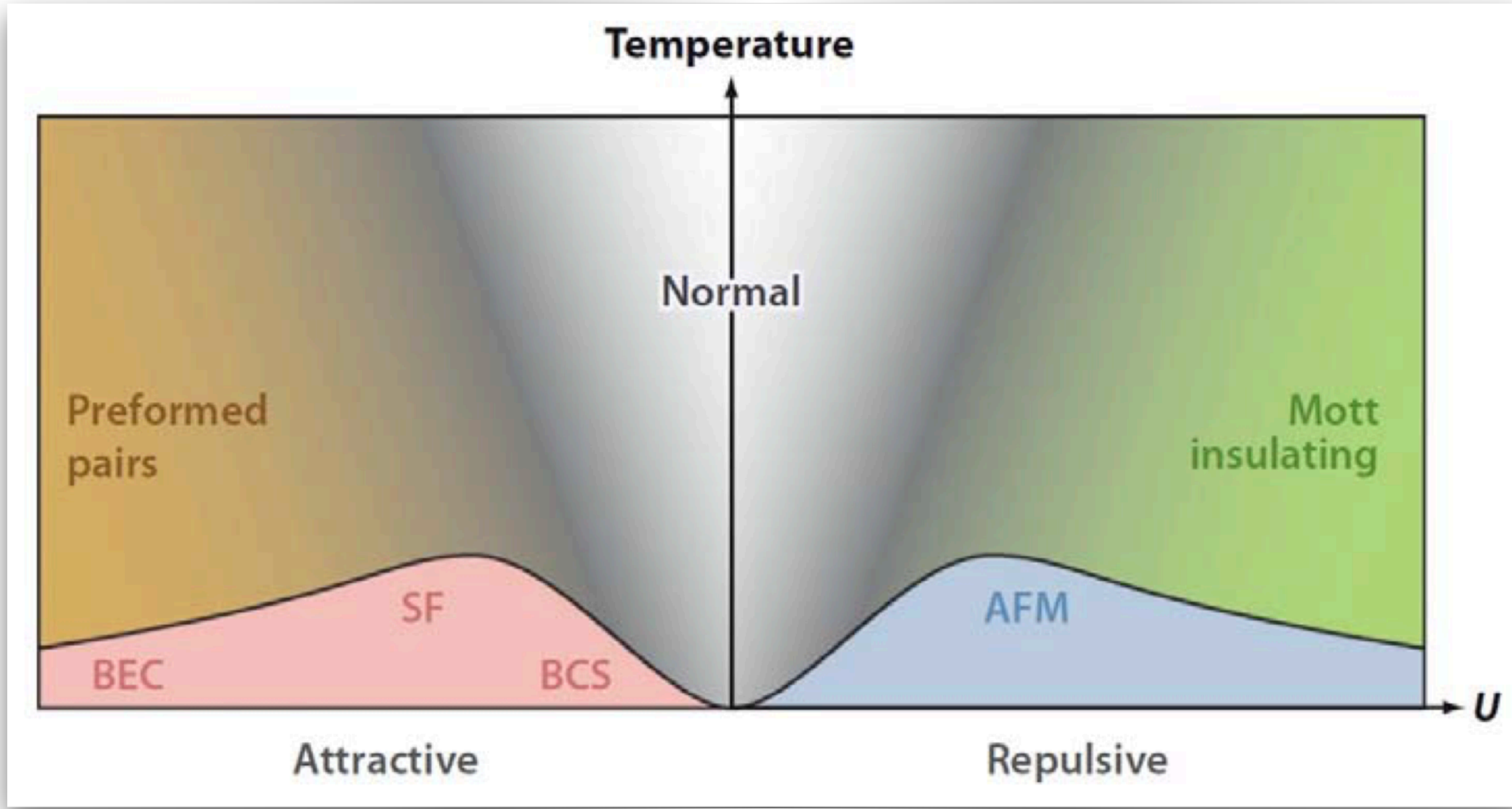
Fermionic Mott insulator



2D cubic lattice under the microscope

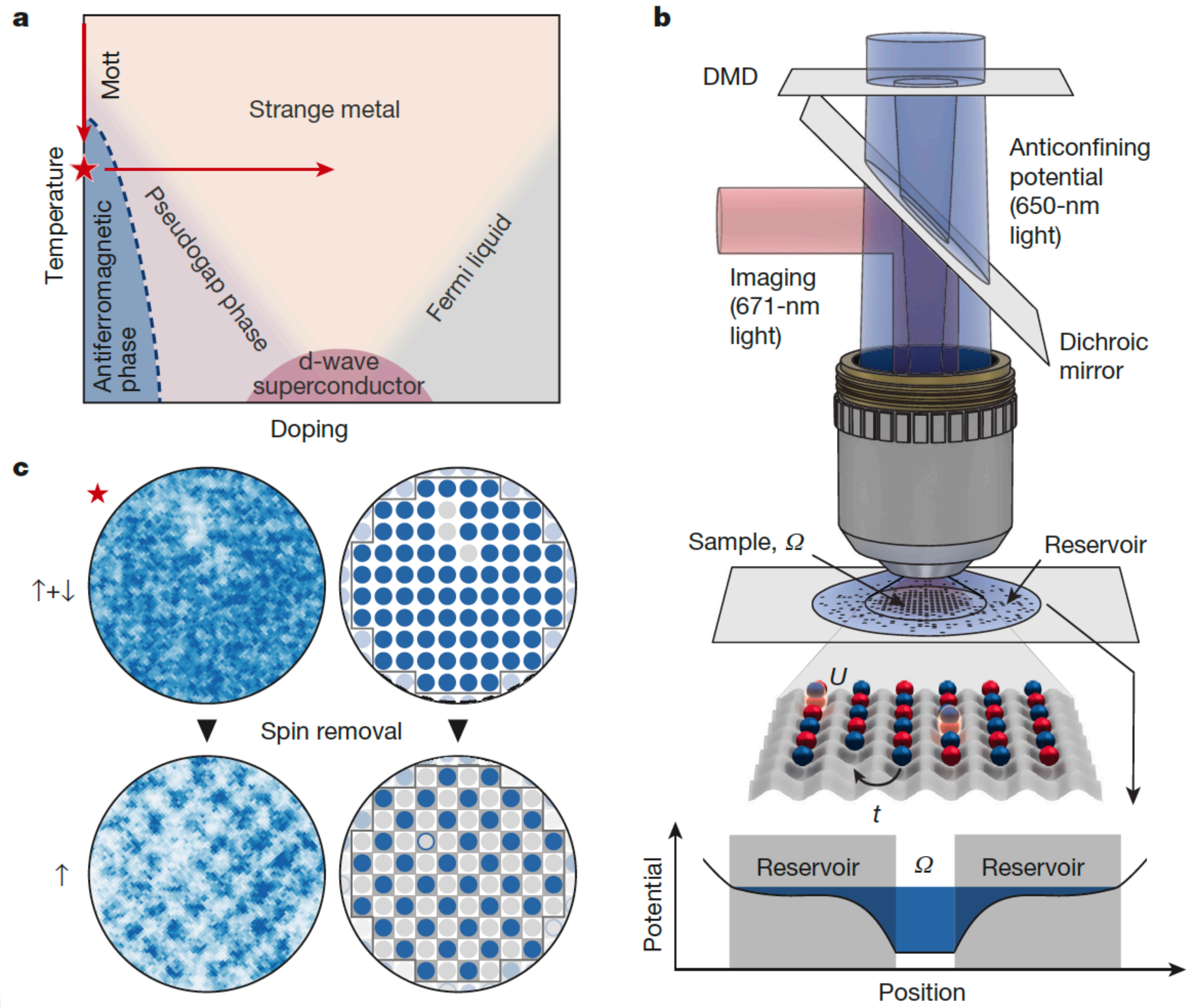
*Greif et al. Science **351**, 953 (2016)*

Phase diagram at half-filling



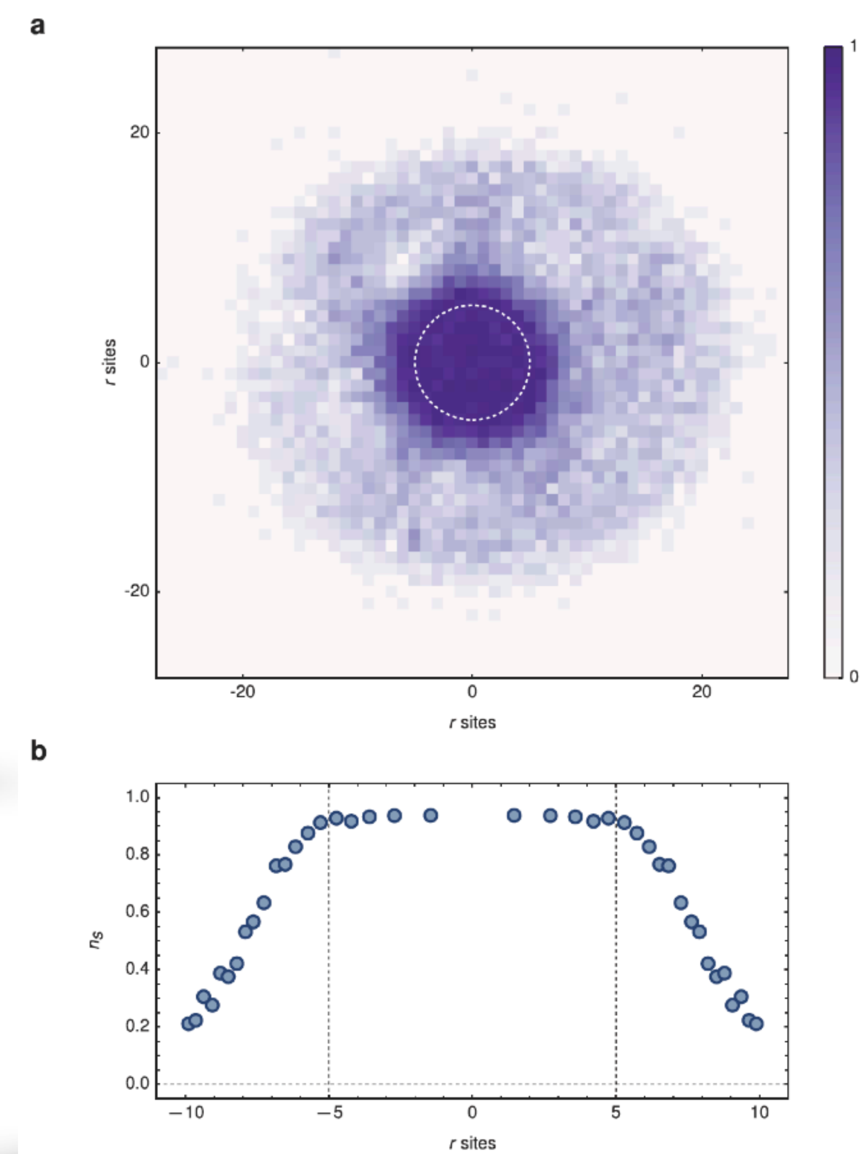
Esslinger, Ann. Rev. Cond. Matter Phys. ***1****, 129 (2010)*

Antiferromagnetic order

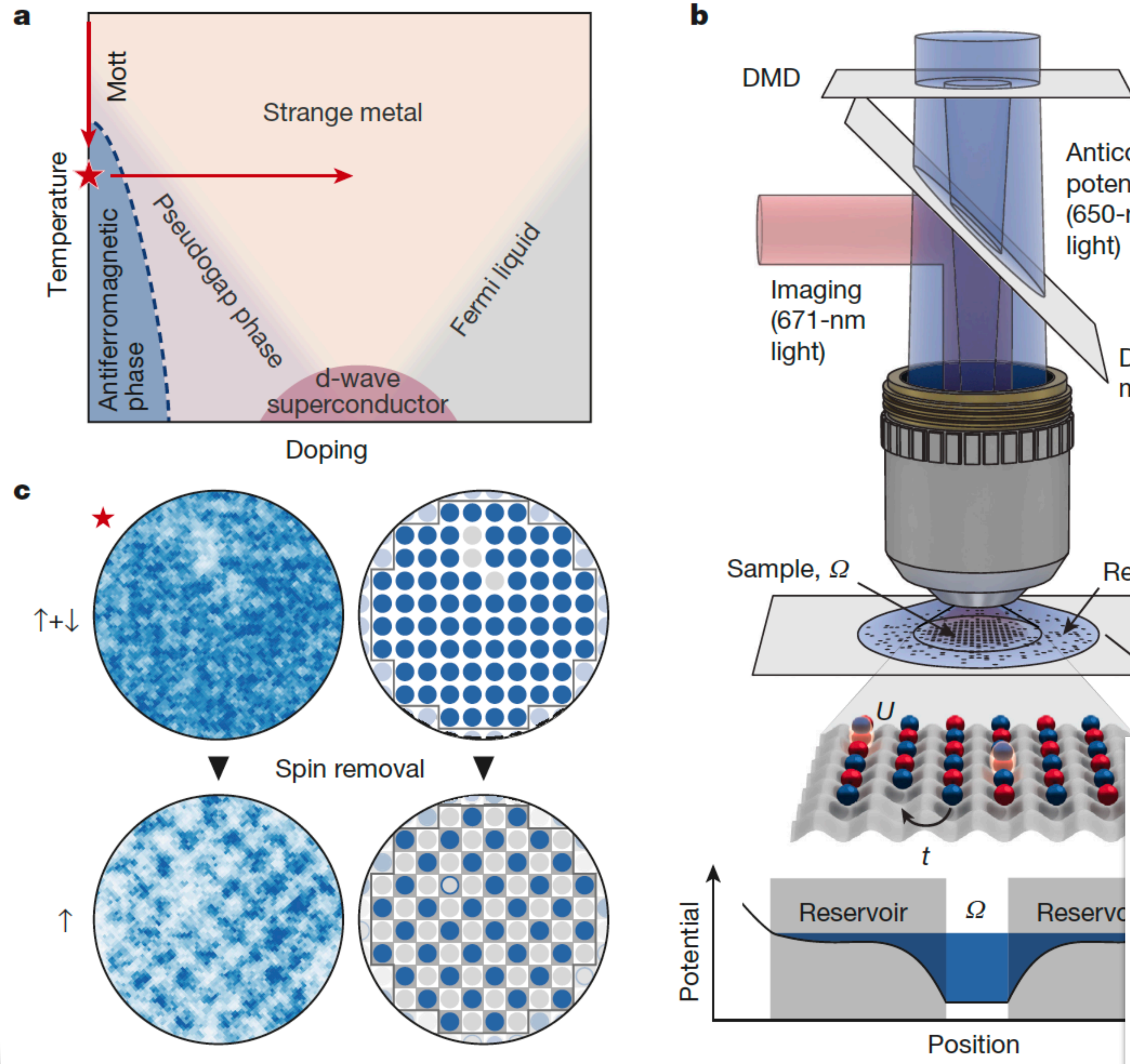


Mazurenko et al. Science **545**, 462 (2017)

Low entropy region only in the central region of the trap



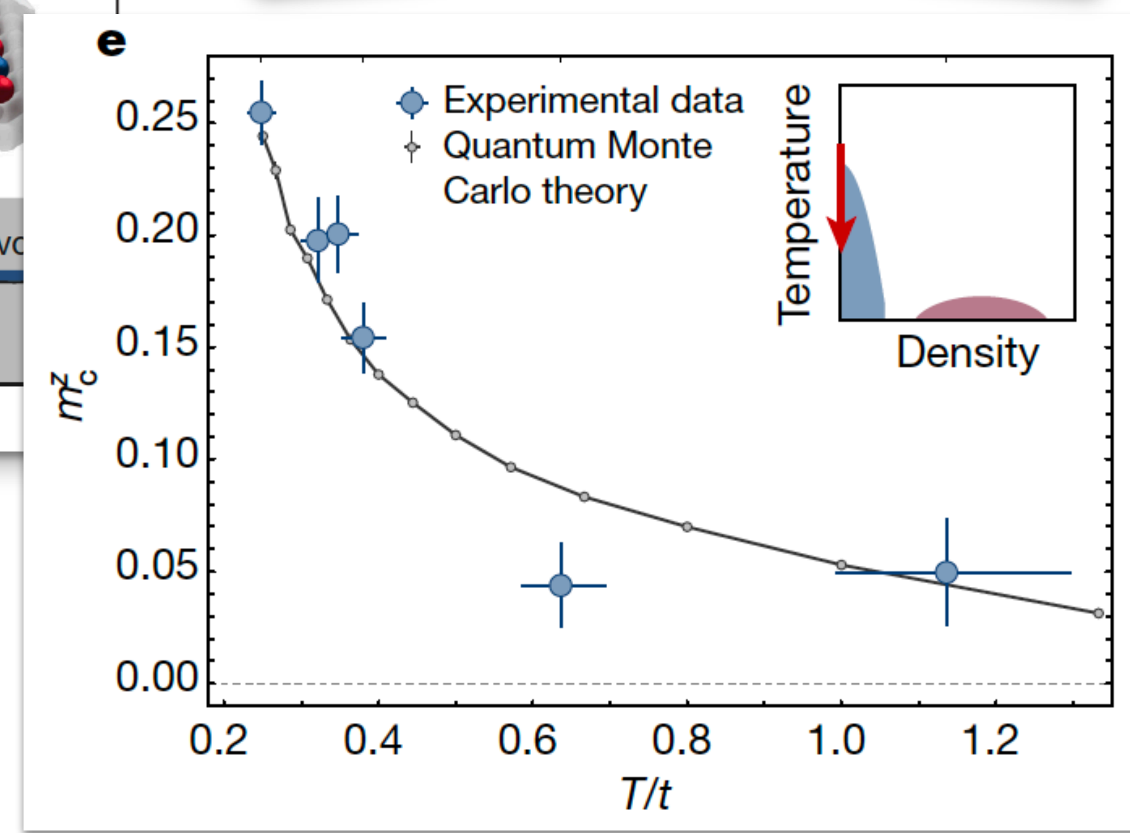
Antiferromagnetic order



Staggered magnetisation

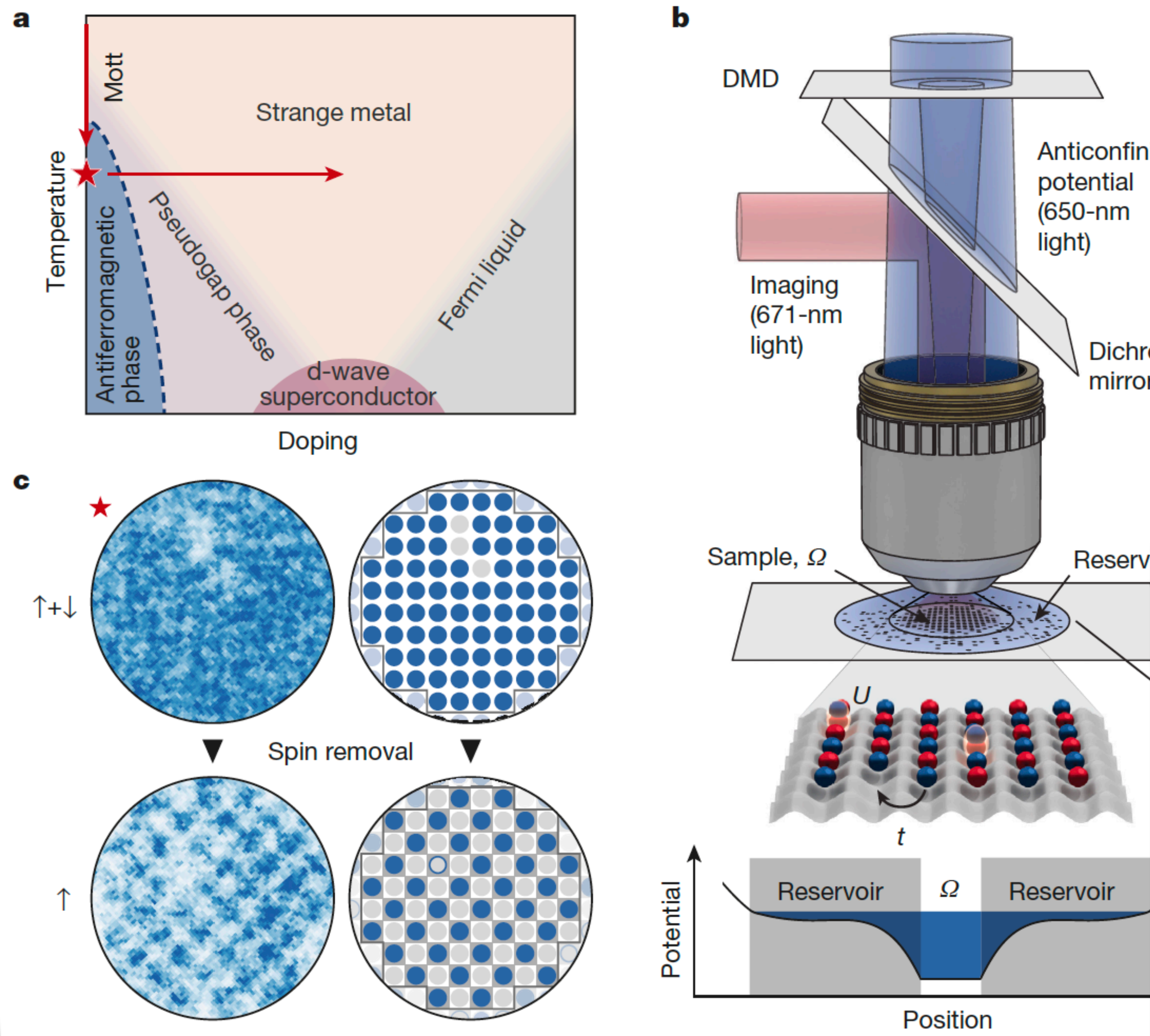
$$\vec{m} = \frac{1}{N_s} \sum_j \vec{S}_j \times (-1)^{x_j + y_j + z_j}$$

$$m^z = \sqrt{\langle (\hat{m}^z)^2 \rangle} = \sqrt{\left\langle \left(\frac{1}{N} \sum_i (-1)^i \frac{\hat{S}_i^z}{S} \right)^2 \right\rangle}$$



*Mazurenko et al. Science **545**, 462 (2017)*

Antiferromagnetic order



Staggered magnetisation

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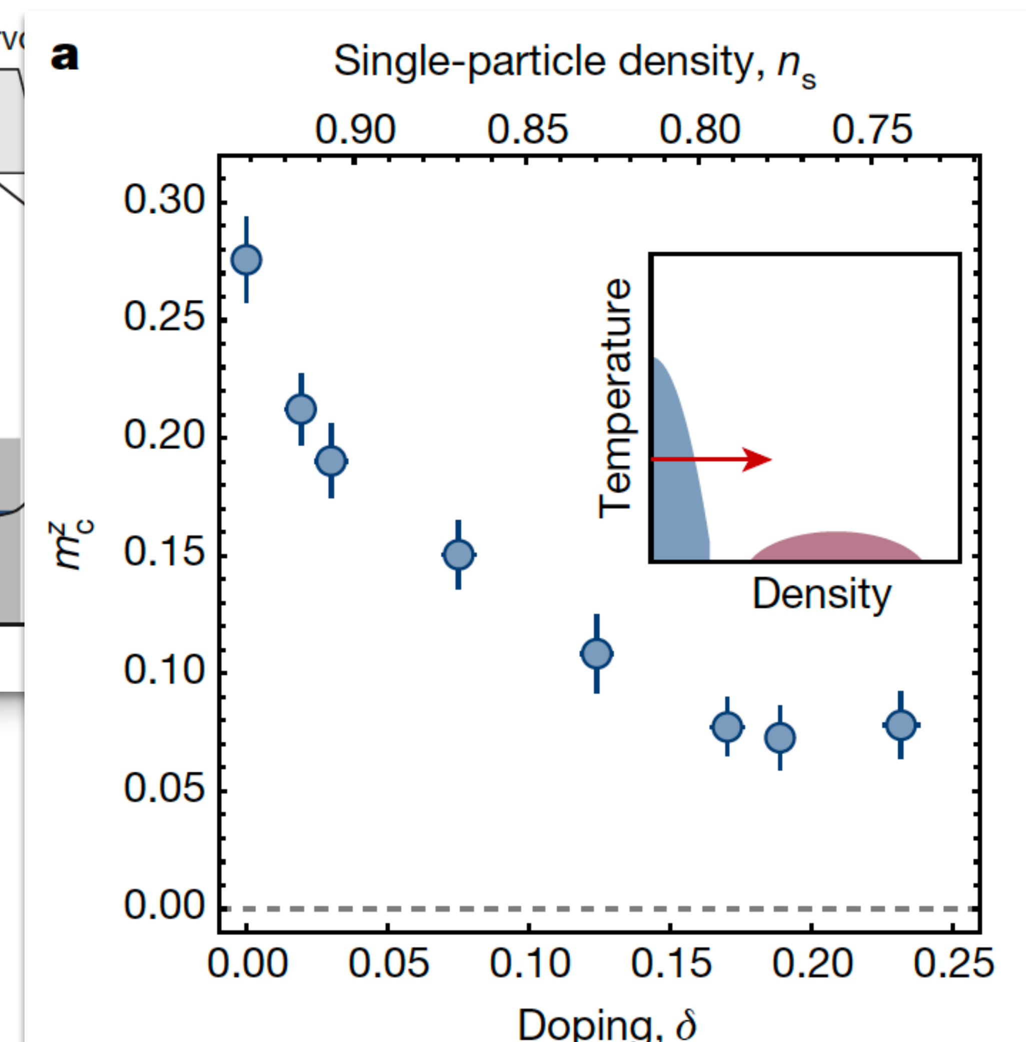
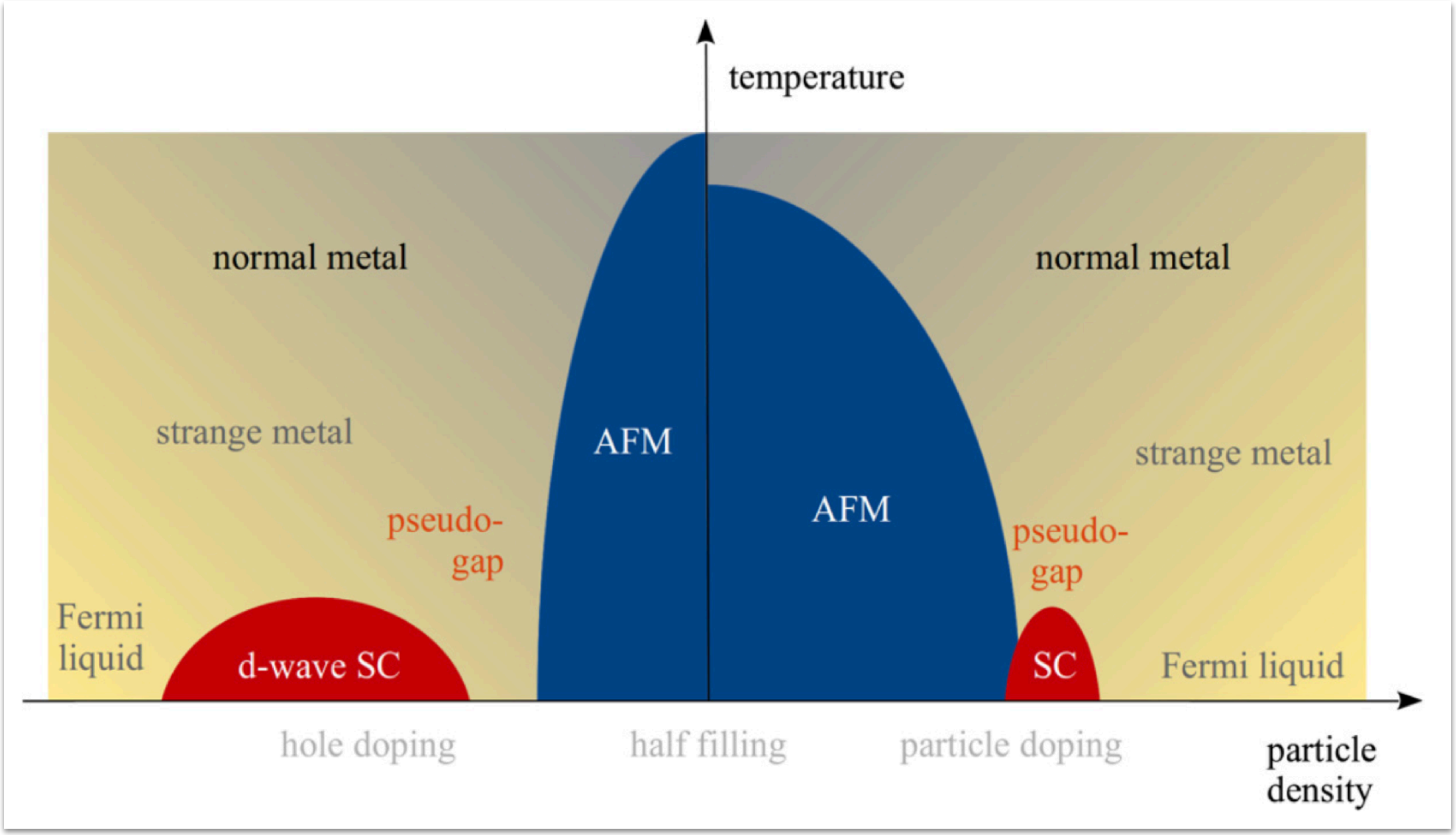


Mazurenko et al. Science ***545****, 462 (2017)*

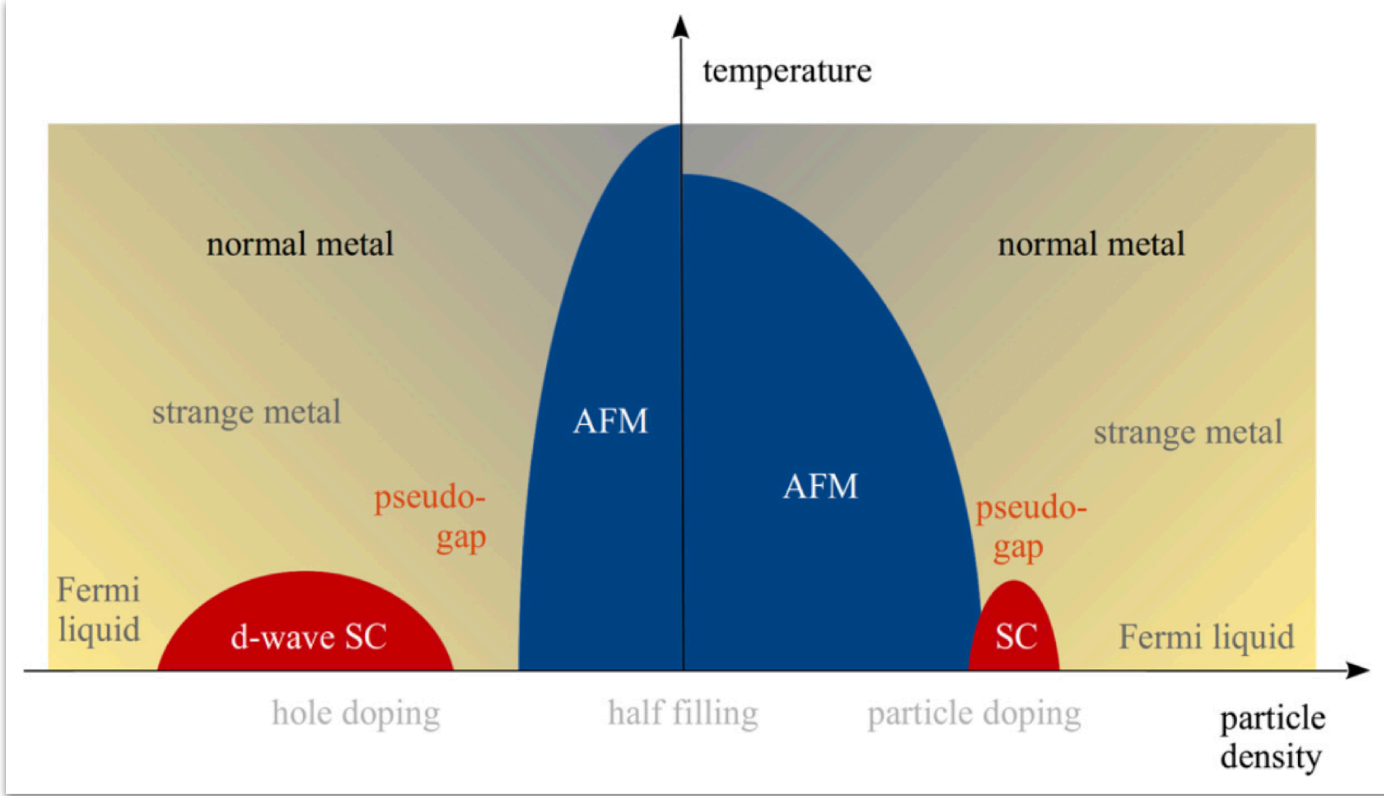
Magnetisation with doping: no theoretical description, **quantum simulation!**

Phase diagram of cuprates



Physics of doped Mott insulators with breaking of particle-hole symmetry

Atomic Fermi-Hubbard: promising perspectives

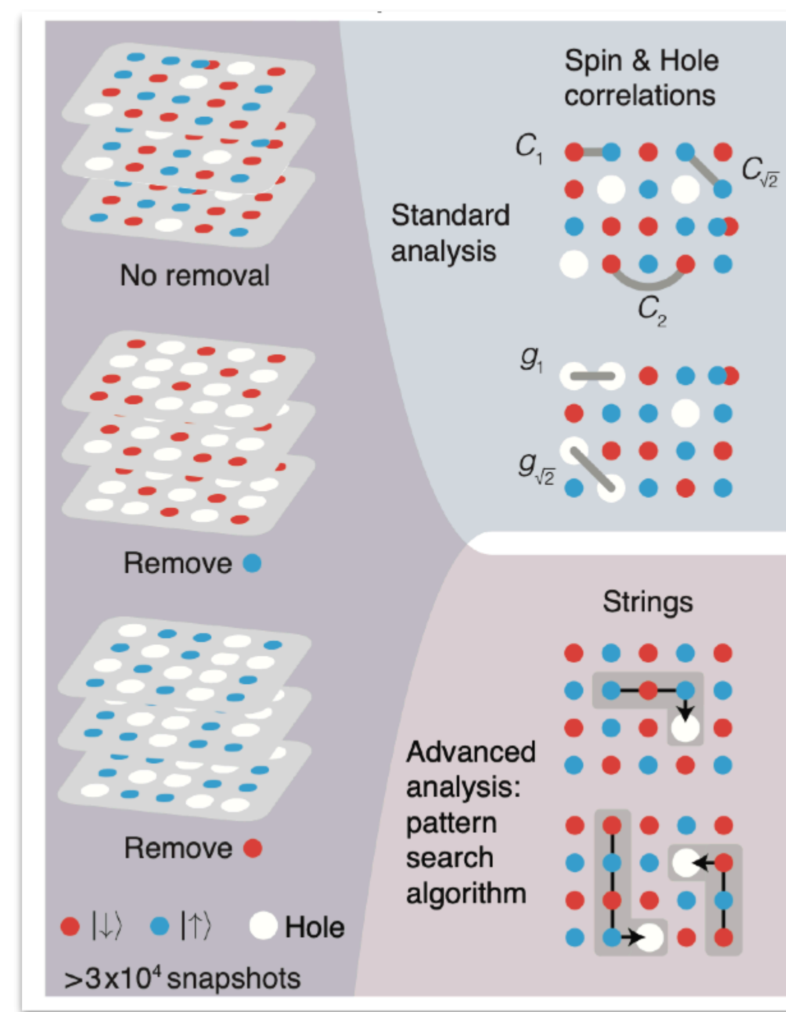


Fermi-Hubbard as a minimal model for high-Tc (strong interaction regime)?

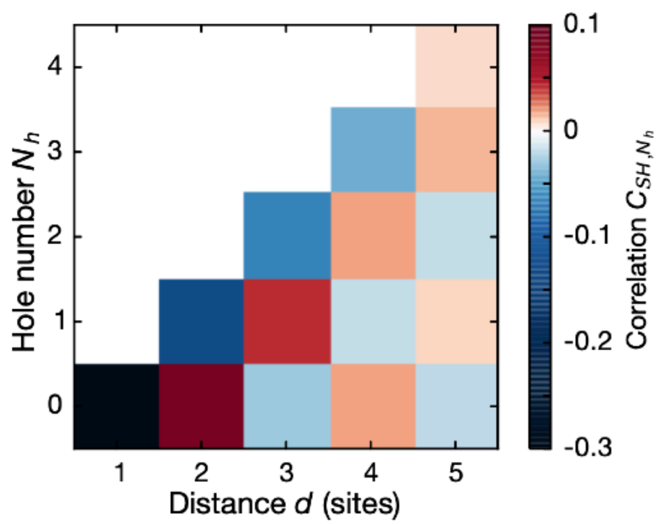
Role of finite doping on spin ordering and transport?

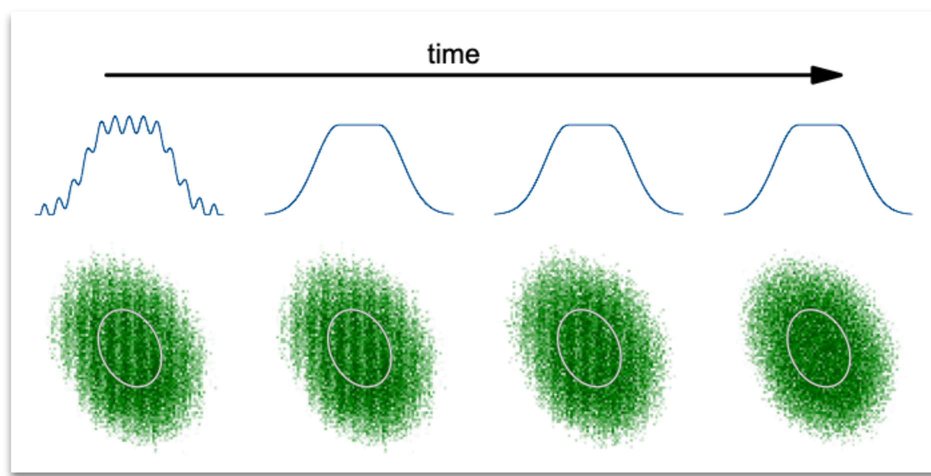
Pseudo-gap and strange metal phase?

Chiu et al. Science ***365****, 251 (2019)*



Hilker et al. Science ***357****, 484 (2017)*





Brown et al. Science ***363****, 379 (2019)*

Koepsell et al. Nature ***572****, 358 (2019)*