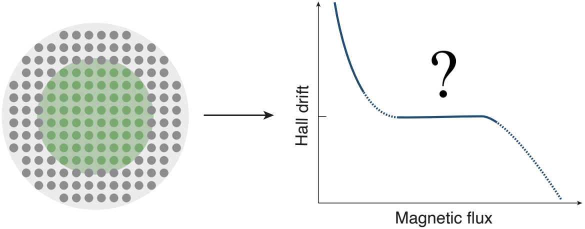
Hall drift of fractional Chern insulators in few-boson systems

Nathan Goldman



Cécile Repellin, Julian Léonard and NG, Phys. Rev. A **102,** 063316 (2020)

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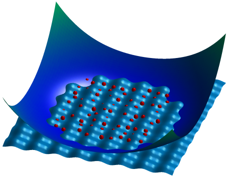
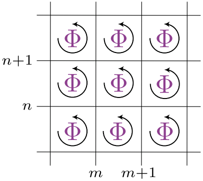
I. Scope and motivations

Ultracold atoms and the Harper-Hofstadter model

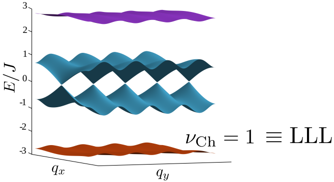
Ultracold gas in optical lattice



artificial magnetic flux



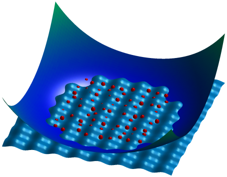
Chern bands



Cold atoms : Cooper, Dalibard, Spielman, RMP ’19
Photonics : Ozawa et al., RMP ’19

- ## Ultracold atoms and the Harper-Hofstadter model

Ultracold gas in optical lattice



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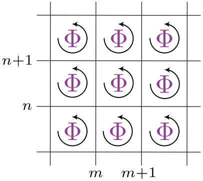

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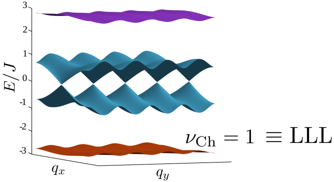

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- ## A setting for fractional quantum Hall physics

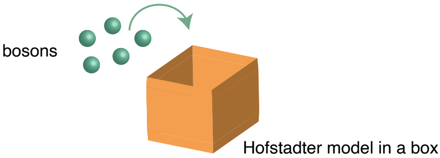
Bosons with strong repulsive interactions at filling factor $\nu = 1/2$

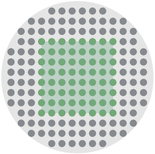
$\longrightarrow$ fractional Chern insulator (**FCI**) akin to the **Laughlin state**

Theory : Sørensen, Demler and Lukin PRL **94** 086803 (2005)

- **Experimental strategy**

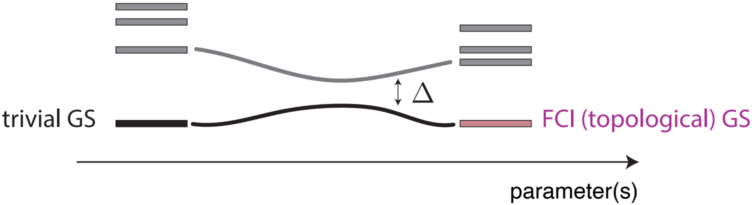
Prepare $N \sim 3 - 10$ interacting bosons in few sites (**box** potential)





$N = 2$: Greiner's group, Nature **546** 519 (2017)

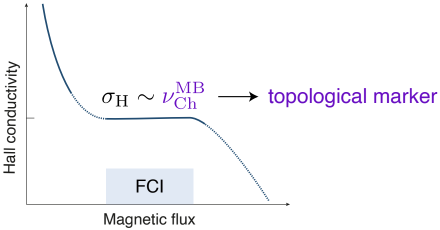
Adiabatic quantum state engineering :



Theory : He, Grusdt et al. PRB **96** 201103 (2017) ; Motruk and Pollmann PRB **96** 165107 (2017)

- **Question :** Phase diagram of this setting ?

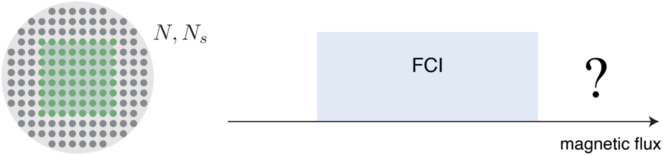
- **Question :** FCI state revealed by **Hall plateau** ?



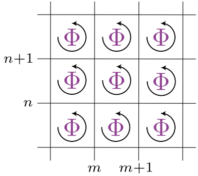
- **Question :** Practical methods to **extract the Hall response** ?

Ref : Repellin, Leonard, Goldman PRA **102** 063316 (2020)

II. Phase diagram



- **Model :** Harper-Hofstadter model



N hardcore bosons in N_s sites $\longrightarrow$ $\rho = N/N_s$: particle density

α : flux quanta per cell (flux density) $\longrightarrow$ $\boxed{\nu = \rho/\alpha \text{ : filling factor}}$

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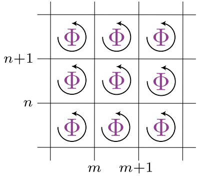

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Theory : Hafezi, Sørensen, Demler and Lukin PRA **76** 023613 (2007)

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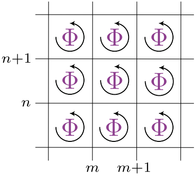

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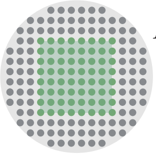
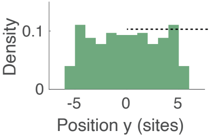
- **Box (OBC) :** Filling factor in the bulk $\nu_{\text{bulk}} = \rho_{\text{bulk}}/\alpha$



N, N_s

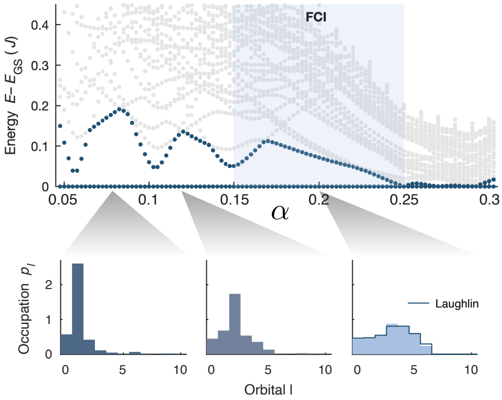


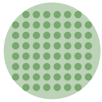
$\rho_{\text{bulk}} = \rho_{\text{bulk}}(\alpha)$

$\neq N/N_s$

$\longrightarrow$ difficult to predict FCI regime for small systems !

- **Ground state analysis** for $N = 4$ bosons in $N_s = 60$ lattice sites





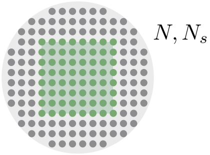
- Avoided crossings : finite-size signatures of phase transitions

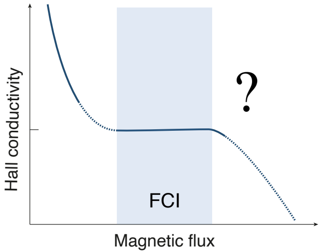
- In the range $\alpha = 0.15 - 0.25$: phase compatible with **FCI**

- **Topology of FCI candidate** : confirmed by particle entanglement spectrum

Ref : Repellin, Leonard, Goldman PRA **102** 063316 (2020)

III. Quantized Hall response





- **Hall response** in small atomic system ?

  Issues : local currents fluctuate, edge effects, ...

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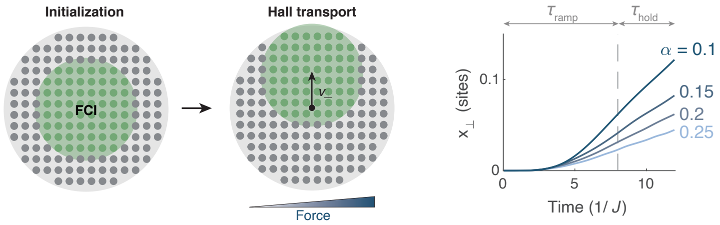
$\Longrightarrow$ monitor **center-of-mass** Hall drift upon **release** into larger lattice

Ref : Dauphin and Goldman, PRL **111** 135302 (2013)



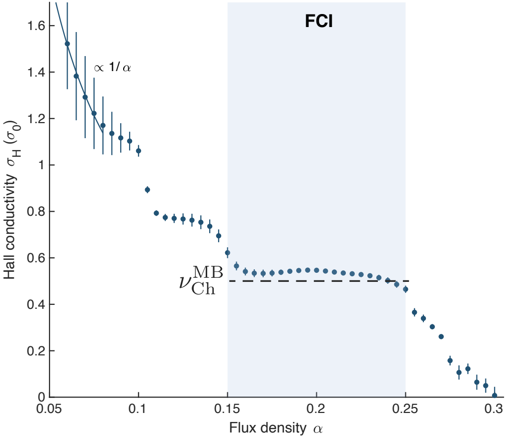
- **Transport equation**

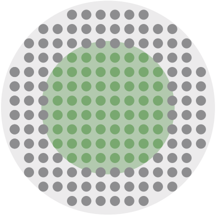
$$\sigma_{\mathrm{H}}/\sigma_0 = (2\pi\rho_{\mathrm{bulk}}/F)\, v_\perp, \qquad \sigma_0 = 1/2\pi$$

$\longrightarrow$ Measure σ_{H} from **Hall drift ($v_\perp$)** and **bulk density (ρ_{bulk})**

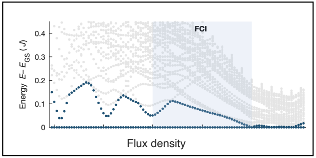
Ref : Repellin, Leonard, Goldman PRA **102** 063316 (2020)

- **Hall conductivity from Hall drift** ($N = 4$ bosons in $N_s = 60$ sites)





Ground-state analysis

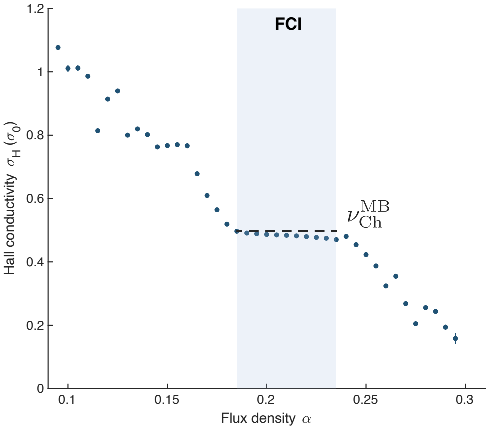


- **Hall plateau** at $\sigma_{\mathrm{H}}/\sigma_0 \approx 1/2 \rightarrow$ **topological marker for FCI** at $\nu = 1/2$
- Width of the plateau compatible with GS properties (many-body gap, PES)

Ref : Repellin, Leonard, Goldman PRA **102** 063316 (2020)

- **Convergence of Hall plateau** at $\sigma_{\rm H}/\sigma_0 \approx 1/2$

DMRG results for $N = 10$ bosons in $N_s = 120$ lattice sites :



Hall drift : practical method to estimate **many-body Chern number** of few-boson FCIs

Ref : Repellin, Leonard, Goldman PRA **102** 063316 (2020)

- **Density response** to magnetic perturbations

Streda's formula : $\sigma_{\mathrm{H}}/\sigma_0 = \frac{\partial \rho_{\mathrm{bulk}}}{\partial \alpha}$ within an incompressible phase

$\longrightarrow$ measuring **bulk density** $\rho_{\mathrm{bulk}}(\alpha)$ **reveals FCI !**

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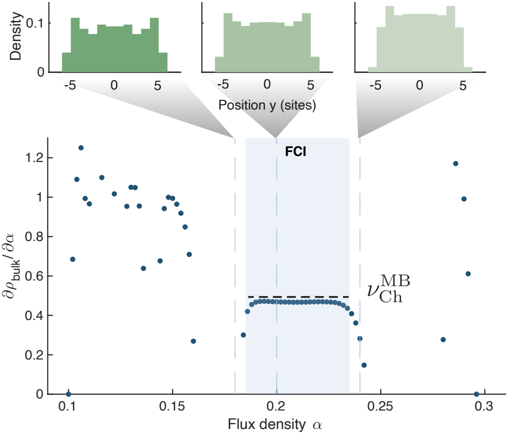

- The "**Streda plateau**" perfectly matches the Hall-drift plateau !

Ref : Repellin, Leonard, Goldman PRA **102** 063316 (2020)

- **Take-home message 1** :

  Center-of-mass Hall drift reveals quantized plateaus in few-boson settings

$\longrightarrow$ Hall drift provides a **practical topological marker**

see also the talk by **Johannes Motruk** (Friday, Session **X27**)

- **Take-home message 2** :

  Density response (Streda) yields clear Hall plateau for $N \gtrsim 10$ bosons

$\longrightarrow$ Measuring $\rho_{\mathrm{bulk}}(\alpha)$ provides a **practical topological marker**

Reference : Repellin, Leonard, Goldman PRA **102** 063316 (2020)

Slides are available : https ://www.nathan-goldman-physics.com/news