Max-Planck Institute for the Science of Light

11.03.2021

Seminar Talk

Topological states in real and synthetic quantum matter

Tobias Grass

ICFO

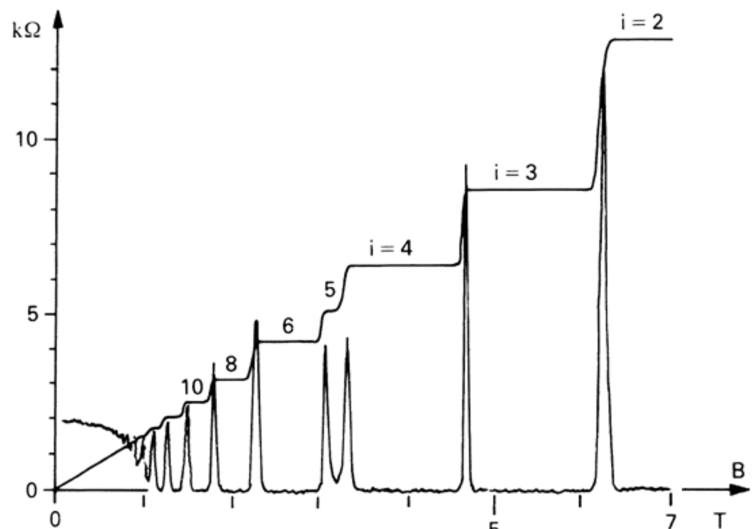
Fundación "la Caixa"
Generalitat de Catalunya
Fundació Privada CELLEX
Fundació Privada MIR-PUIG
Ministerio de Economía, Industria y Competitividad
Excelencia Severo Ochoa
NSF

Topology and symmetry

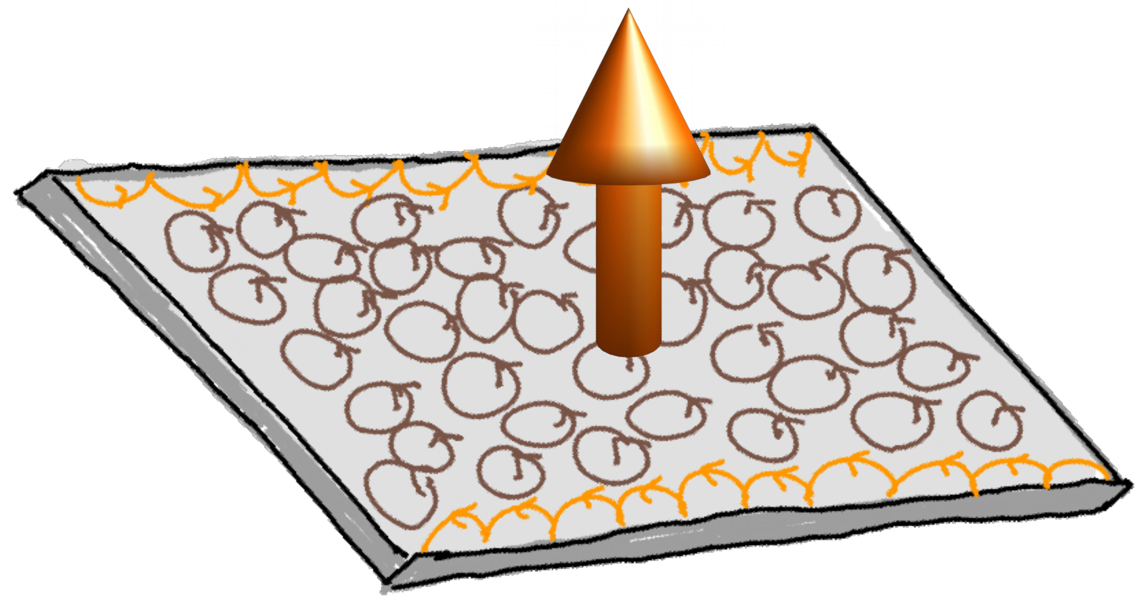
Topology and symmetry

Quantum Hall Systems

Robust transport property:
quantized Hall resistance



© Royal Society



Magnetic field defines topology→ chiral motion leads to robust edge transport


1985

[von Klitzing, Dorda, Pepper, PRL (1980)]

Topological invariant from band curvature:

$$C = \frac{i}{2\pi} \int d\mathbf{k} \left\langle \frac{\partial u^*_{\mathbf{k}}(\mathbf{r})}{\partial \mathbf{k}} \right| \times \left| \frac{\partial u_{\mathbf{k}}(\mathbf{r})}{\partial \mathbf{k}} \right\rangle$$

⟷

Kubo formula:

$$\sigma_{\mathrm{H}} = \frac{e^2}{h} C$$

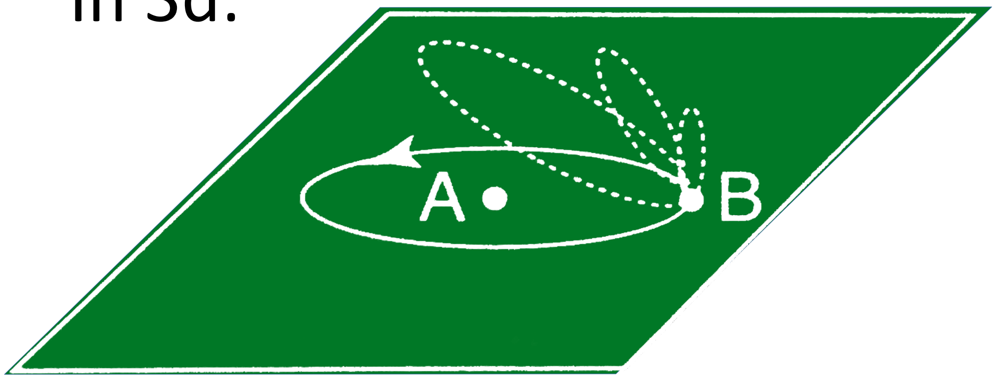

2016

[Thouless, Kohmoto, Nightingale, den Nijs, PRL (1982)]

Anyons and non-Abelions

- Topological band structure (in 1d or 2d) + interactions:
  → Emergence of exotic quasiparticle ("anyons")

In 3d:

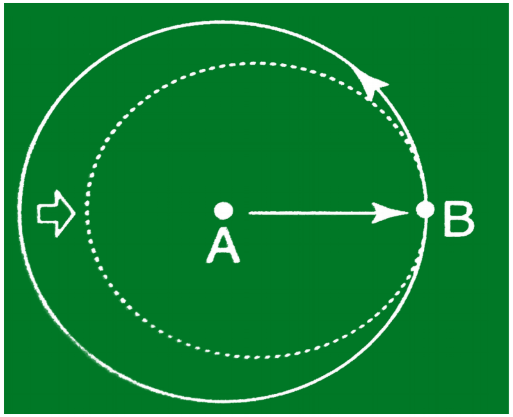


Double Exchange = Identity

➡ Bosons or Fermions

$$\Psi_{AB} = \pm \Psi_{BA}$$

In 2d:



Double Exchange non-trivial

➡ Anyons

$$\Psi_{AB} = \exp(i\theta)\Psi_{BA}$$

- If anyonic states are degenerate, exchange corresponds to rotations within the degenerate space ➡ non-Abelion anyons

[Leinaas & Myrheim, Il Nuovo Cimento B (1977)] **[Nayak, Simon, Stern, Freedman, Das Sarma, RMP (2008)]**

Fractional Quantum Hall Effect

1998 Tsui, Stoermer, Laughlin

- Hall conductance $\sigma_{\mathrm{H}} = \frac{e^2}{h} C$ quantized to fractional values:

$$C = n \Rightarrow \quad \text{Integer Quantum Hall Effect}$$

$$C = \frac{p}{q} \Rightarrow \quad \text{Fractional Quantum Hall Effect}$$

$$n, p, q \in \mathbb{N}$$

In general: $C = \nu$ (Landau level filling)

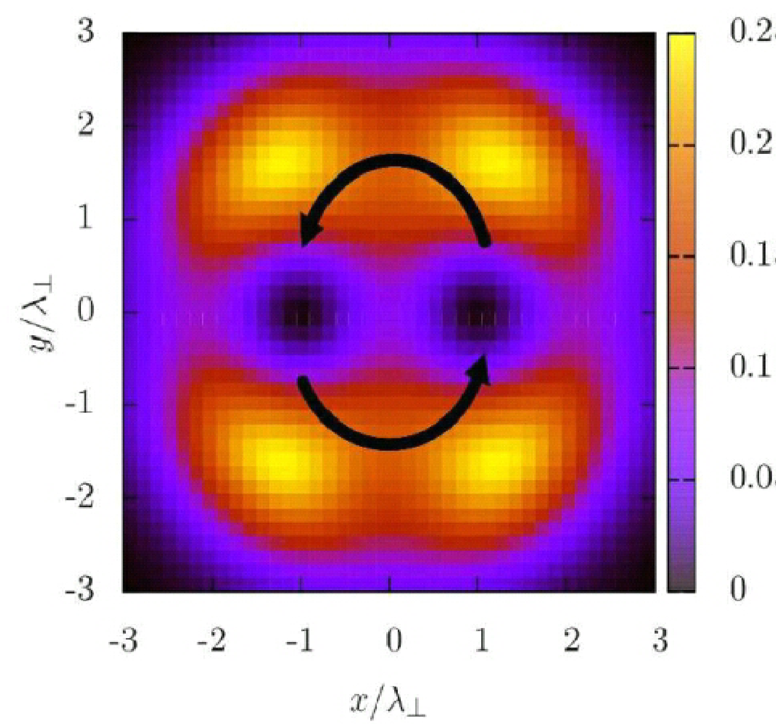
→ integer filling: HUGE single-particle gap

→ fractional filling: NO single-particle gap

- Interactions can yield strongly anticorrelated and gapped states

  Examples: Laughlin state, Pfaffian state, …

- Bulk excitations (e.g. quasiholes) behave like anyons
- Goal: experimental demonstration



[Julia-Diaz, TG, Barberan, Lewenstein, New J. Phys. 14, 055003 (2012)]

Outline of the talk

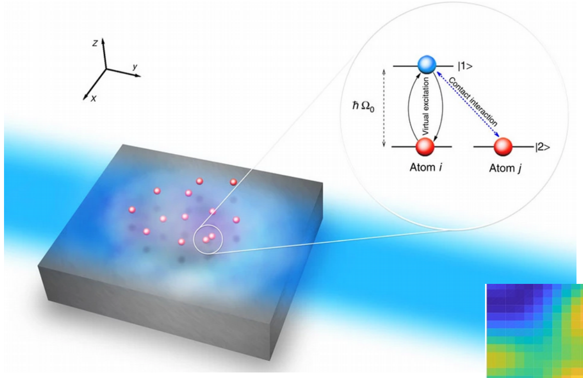
- Fractional Quantum Hall physics in synthetic matter:

➔ Engineering of Hamiltonian

Synthetic gauge fields

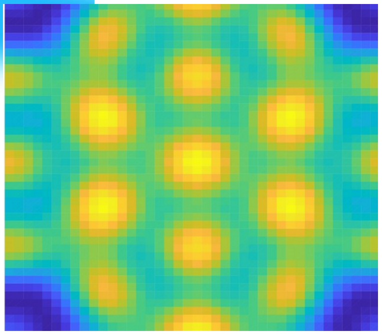
➔ Preparation of ground state

Adiabatic scheme



➔ Reward of these efforts:

- enhanced detection opportunities (anyon detection)
- engineering of exotic phases (fractional Wigner crystal)



- Fractional Quantum Hall physics in electronic matter:

➔ Monolayer graphene in *B* field:

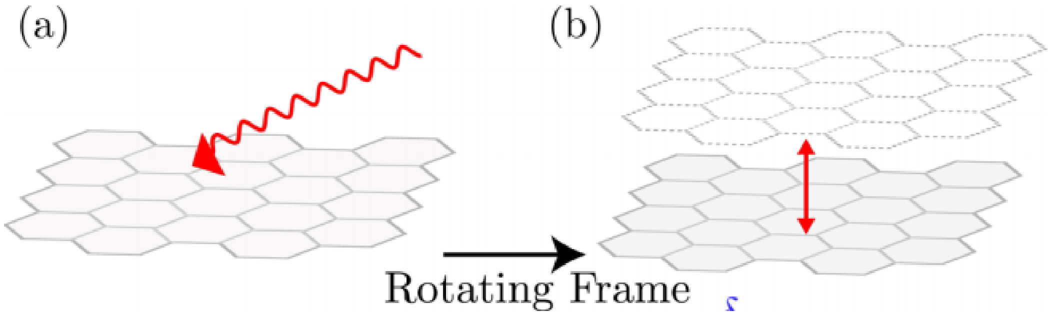
Laughlin state

➔ Optical driving:

synthetic bilayer structure

➔ Reward:

non-Abelian Fibonacci anyons



Synthetic FQH matter: preparation

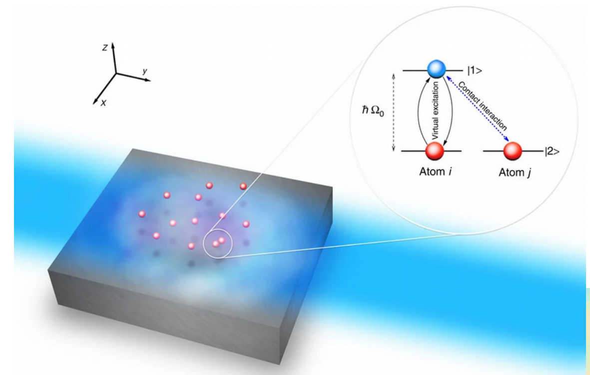
- Fractional Quantum Hall physics in synthetic matter:

→ **Engineering of Hamiltonian**

Synthetic gauge fields

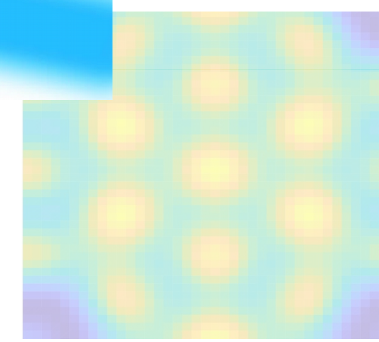
→ **Preparation of ground state**

Adiabatic scheme



→ Reward of these efforts:

- enhanced detection opportunities (anyon detection)
- engineering of exotic phases (fractional Wigner crystal)



- Fractional Quantum Hall physics in electronic matter:

→ Monolayer graphene in *B* field:

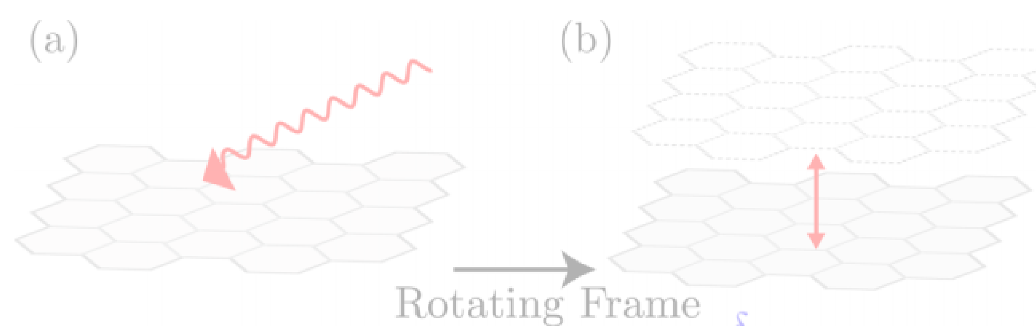
Laughlin state

→ Optical driving:

synthetic bilayer structure

→ Reward:

non-Abelian Fibonacci anyons



Synthetic gauge fields

- Mimic effect of magnetic field in charge-neutral systems:

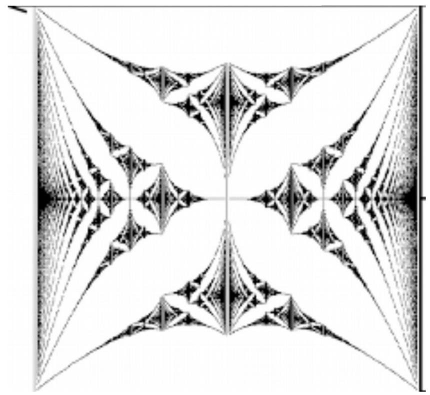
  (cold atoms, photons, etc.)

  - Optical techniques

    Cold atoms in trap: [Lin,..., Spielman, Nature (2009)]
    Cold atoms in lattice: [Aidelsburger,..., Bloch, PRL (2013)]
    [Miyake,...,Ketterle, PRL (2013)]
    Coupled resonators: [Hafezi ...,Taylor, Nat. Phys. (2011)]
    Modulated SC qubits: [Roushan, ..., Martinis, Nat. Phys. (2016)]
    Modulated ions: [TG, ..., Lewenstein, PRA (2018)]

  - Mechanical techniques

    Optomechanical lattices: [Schmidt,...,Marquardt, Optica (2015)]
    Lattice shaking: [Struck,...,Sengstock, PRL (2012)]
    Rotating gases: [Matthews, ..., Cornell, PRL (1999)]
    [Madison,..., Dalibard, PRL (2000)]
    [Abo-Shaeer,..., Ketterle, Science (2001)]
    Rotating lattices: [Gemelke, Sarajlic, Chu, arXiv, (2010)]
    Twisted cavities: [Clark,...,Simon, Nature (2020)]



- Single-particle physics: edge states, Chern numbers
  Hofstadter butterfly, ...
- Many-body physics: would/could support anyons,
  but little explored yet!

Preparation of atomic Laughlin droplet

- Ingredients: - Interactions ✓ (Contact interaction)
  - Synthetic gauge fields ✓ (Rotation)

- But:

having the Hamiltonian $\neq$ having the state

- Way to Laughlin state:

Rotation produces Landau levels spectrum

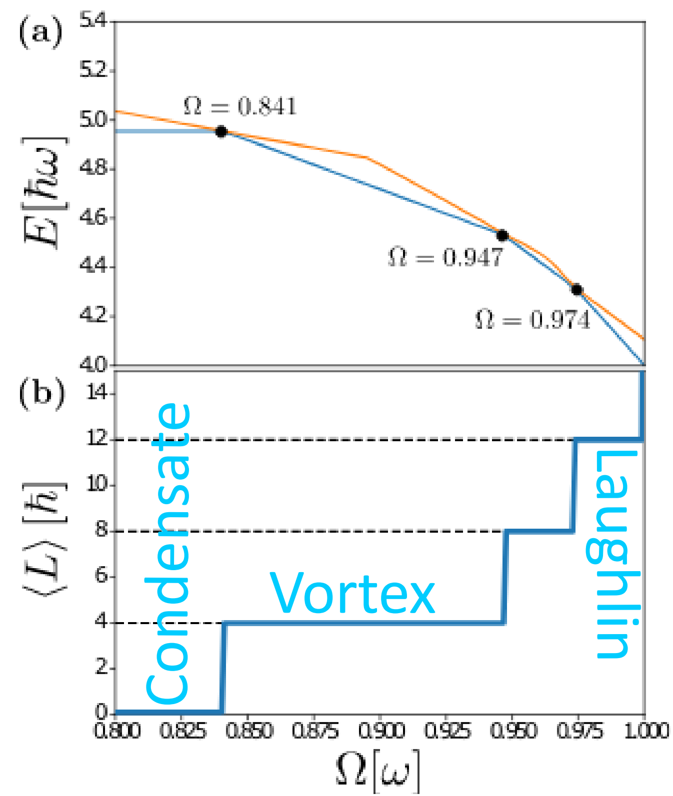
$$E_{nm} = \hbar\left[(\Omega+\omega)n + (\Omega-\omega)m\right] + \text{const.}$$

$(\Omega+\omega) \rightarrow$ "∞" $\qquad (\Omega-\omega) \rightarrow 0$

Rotating faster flattens the Landau levels

↓

Repulsive interactions in a flat band: strongly anticorrelated ground states (vortices, vortex lattices, FQH states)



Behavior of N=4 bosons with contact repulsion (g=1)

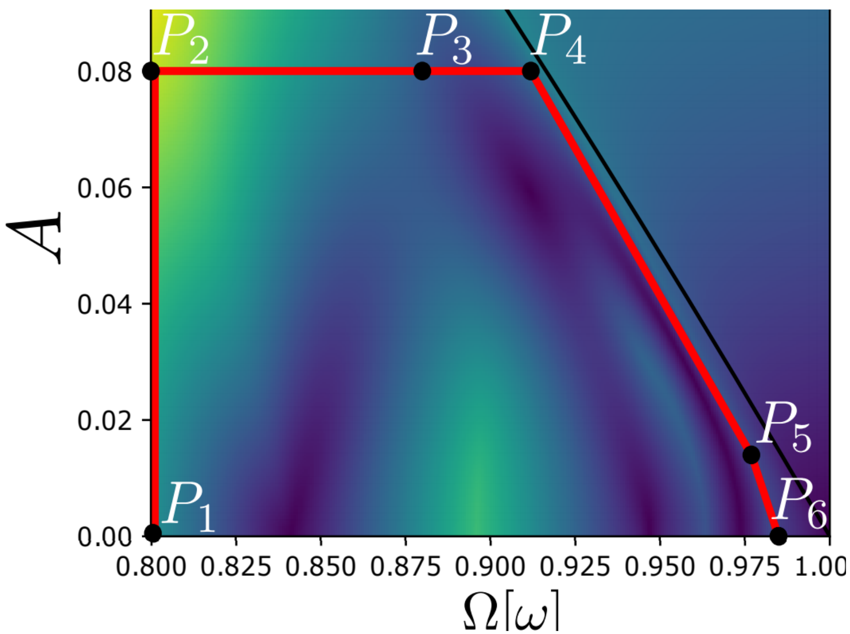
[Popp, Paredes, Cirac, PRA (2004)]
[Dagnino, Barberan, Lewenstein, Dalibard, Nat. Phys. (2009)]
[Andrade, Kasper, Lewenstein, Weitenberg, TG, arXiv 2009.08943]

Preparation of atomic Laughlin droplet

- Ingredients: - Interactions ✓ (Contact interaction)
  - Synthetic gauge fields ✓ (Rotation)

- But: having the Hamiltonian ≠ having the state

- Way to Laughlin: Adiabatic path via anisotropy-induced gaps



Barbara Andrade (ICFO)

Valentin Kasper (ICFO)

Christof Weitenberg (Uni Hamburg)

Maciej Lewenstein (ICFO)

[Popp, Paredes, Cirac, PRA (2004)]
[Dagnino, Barberan, Lewenstein, Dalibard, Nat. Phys. (2009)]
[Andrade, Kasper, Lewenstein, Weitenberg, TG, arXiv 2009.08943]

Synthetic FQH matter: opportunities

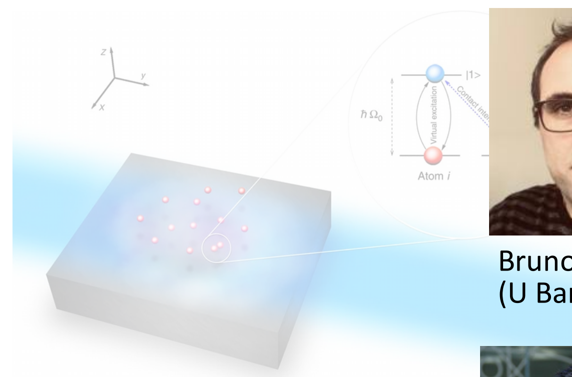
- Fractional Quantum Hall physics in synthetic matter:

  ➔ Engineering of Hamiltonian

  Synthetic gauge fields

  ➔ Preparation of ground state

  Adiabatic scheme

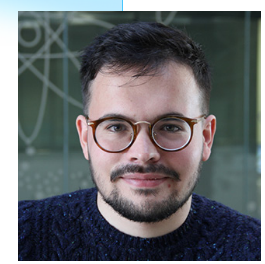
  

  ➔ Reward of these efforts:

  - enhanced detection opportunities (anyon detection)
  - engineering of exotic phases (fractional Wigner crystal)

Bruno Julia-Diaz (U Barcelona)

Utso Bhattacharya (ICFO)



Nicollo Baldelli (ICFO)

Maciej Lewenstein (ICFO)

Fundación "la Caixa"

- Fractional Quantum Hall physics in electronic matter:

  ➔ Monolayer graphene in *B* field:

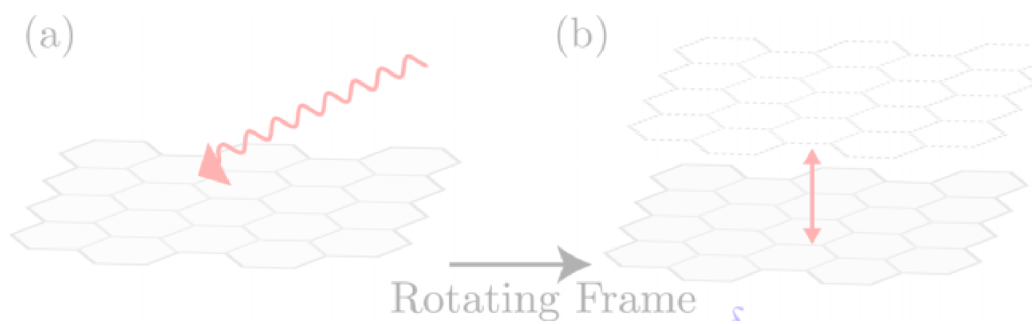
  Laughlin state

  ➔ Optical driving:

  synthetic bilayer structure

  ➔ Reward:

  non-Abelian Fibonacci anyons



Impurities for anyon detection

Probe system with impurity particles binding to anyonic quasiholes

[Zhang, Sreejith, Gemelke, Jain, PRL (2014)]
[Lundholm and Rougerie, PRL (2016)]
[Grusdt, ..., Demler, Nat. Commun. (2016)]
[Yakaboylu and Lemeshko, PRB, (2018)]

- Screening of magnetic field due to the liquid:

$$B^* = B(1-\nu) \;\Rightarrow\; l_B^* = l_B/\sqrt{1-\nu}$$

- Effective Landau level wave functions for the impurities:

$$\tilde{\varphi}_m(w) \sim w^m \exp\left[-(1-\nu)\frac{|w|^2}{4l_B^2}\right]$$ with average angular momentum: $$L_m = \frac{m+\nu}{1-\nu}$$

in contrast to the original wave functions

$$\varphi_m(w) \sim w^m \exp\left[-\frac{|w|^2}{4l_B^2}\right]$$ with angular momentum: $L_m = m$

- Can we use impurity angular momentum to trace anyon behavior?

[TG, Julia-Diaz, Baldelli, Bhattacharya, Lewenstein, Phys. Rev. Lett. 125, 136801 (2020)]

Impurities in Abelian liquids

For multiple impurities, the angular momentum reflects the filling of the single-particle levels:

Fermi sea:

$$L_{\rm F} = \sum_{m=0}^{N_b-1} L_m$$

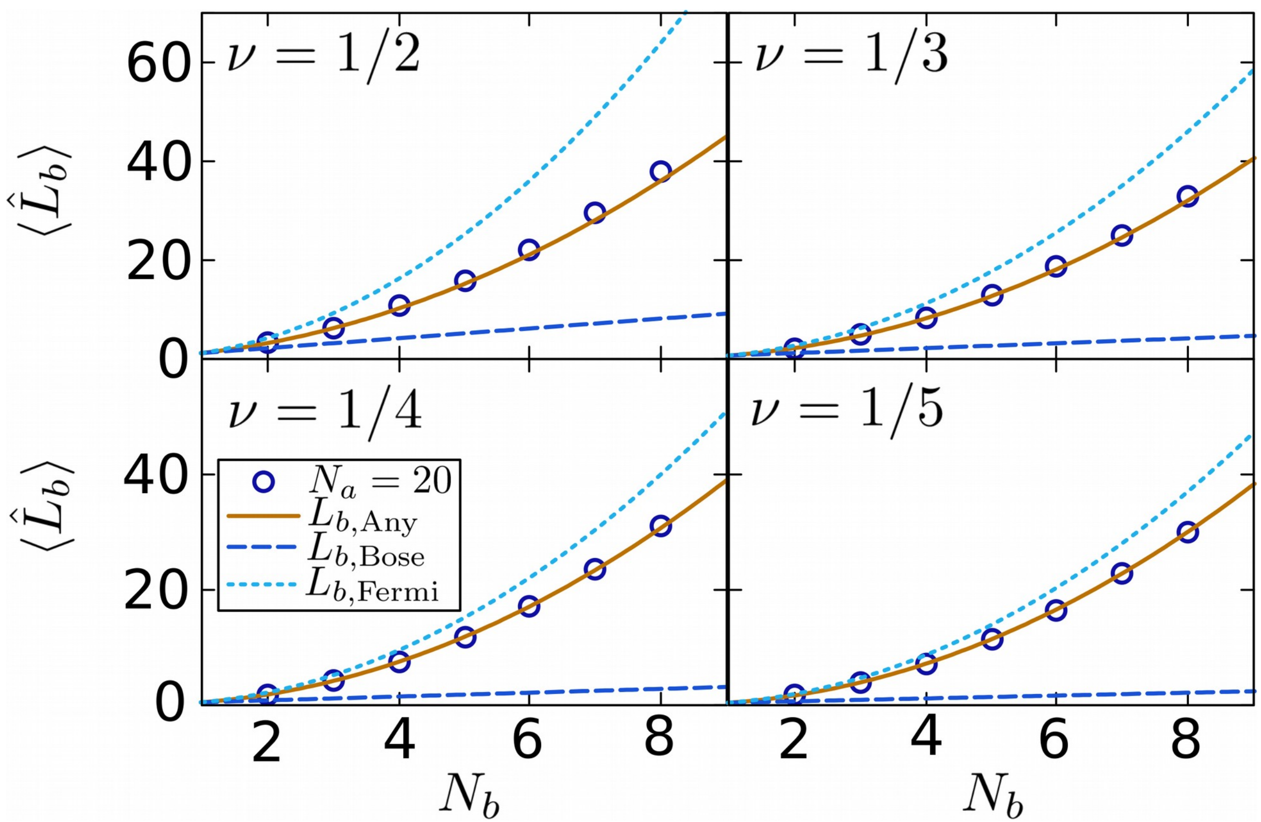
Bose condensate:

$$L_{\rm B} = N_b L_0$$

Anyon gas:

$$L_{\rm A} = (1-\alpha)L_{\rm F} + \alpha L_{\rm B}$$

with statistical parameter α



Detection of α:

No braiding or interference needed, only density measurement!

[TG, Julia-Diaz, Baldelli, Bhattacharya, Lewenstein, Phys. Rev. Lett. 125, 136801 (2020)]

Impurities in non-Abelian liquids

Hallmarks of non-Abelian liquids:

- Quasihole states are degenerate.
- Sensitivity of braiding phase to the parity of the number of particles in the liquid:

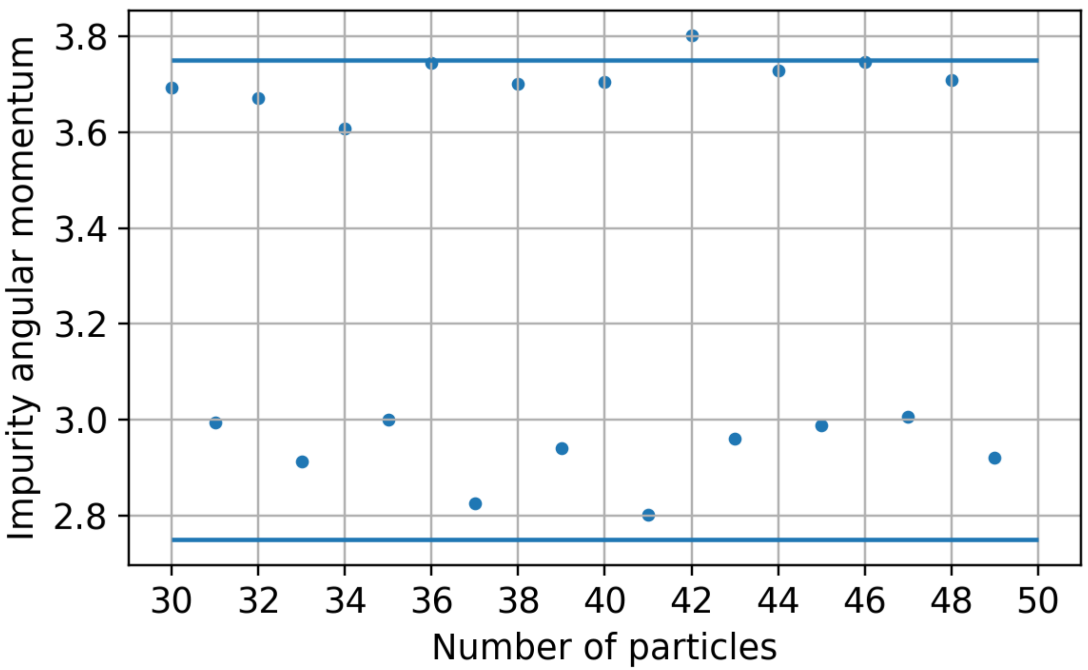
Statistical phase in Pfaffian liquid:

$$\alpha = \frac{\nu}{4} - \frac{1}{8} + \frac{P}{2}$$

[Macaluso, Comparin, Mazza, and Carusotto, PRL (2019)]
[Bonderson, Gurarie, Nayak, PRB (2011)]

Even-odd effect of impurity angular momentum:

[Baldelli, Julia-Diaz, Bhattacharya, Lewenstein, TG, arXiv 2102.02072]



Synthetic FQH matter: opportunities

- Fractional Quantum Hall physics in synthetic matter:

  → Engineering of Hamiltonian

  Synthetic gauge fields

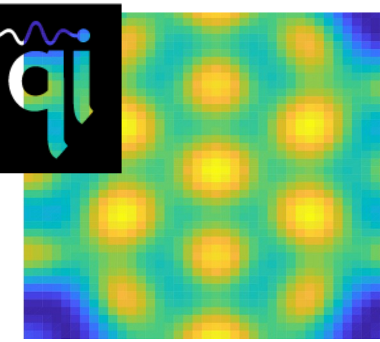
  → Preparation of ground state

  Adiabatic scheme

  → **Reward of these efforts:**

  - enhanced detection opportunities (anyon detection)
  - engineering of exotic phases (fractional Wigner crystal)

Alexey Gorshkov (JQI) | Przemek Bienias (JQI) | Rex Lundgren (JQI) | Michael Gullans (Princeton) | Joseph Maciejko (Alberta)



- Fractional Quantum Hall physics in electronic matter:

  → Monolayer graphene in *B* field:

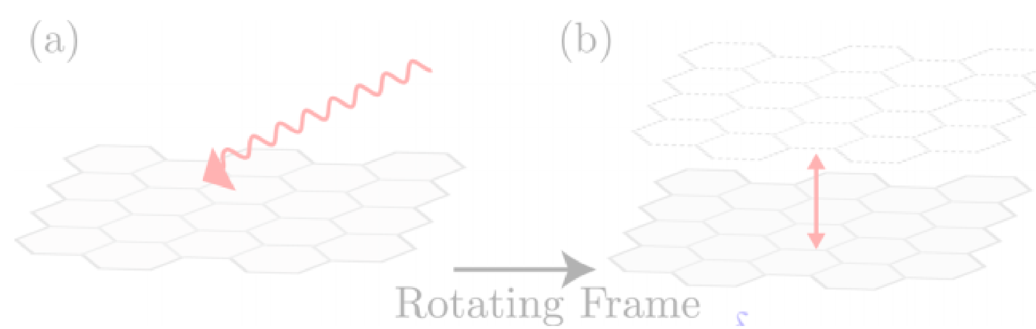
  Laughlin state

  → Optical driving:

  synthetic bilayer structure

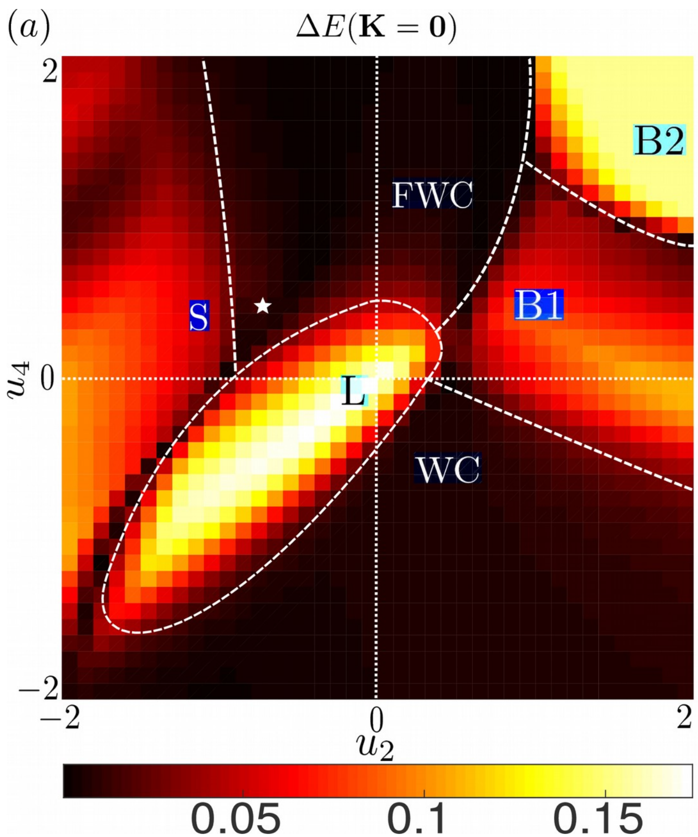
  → Reward:

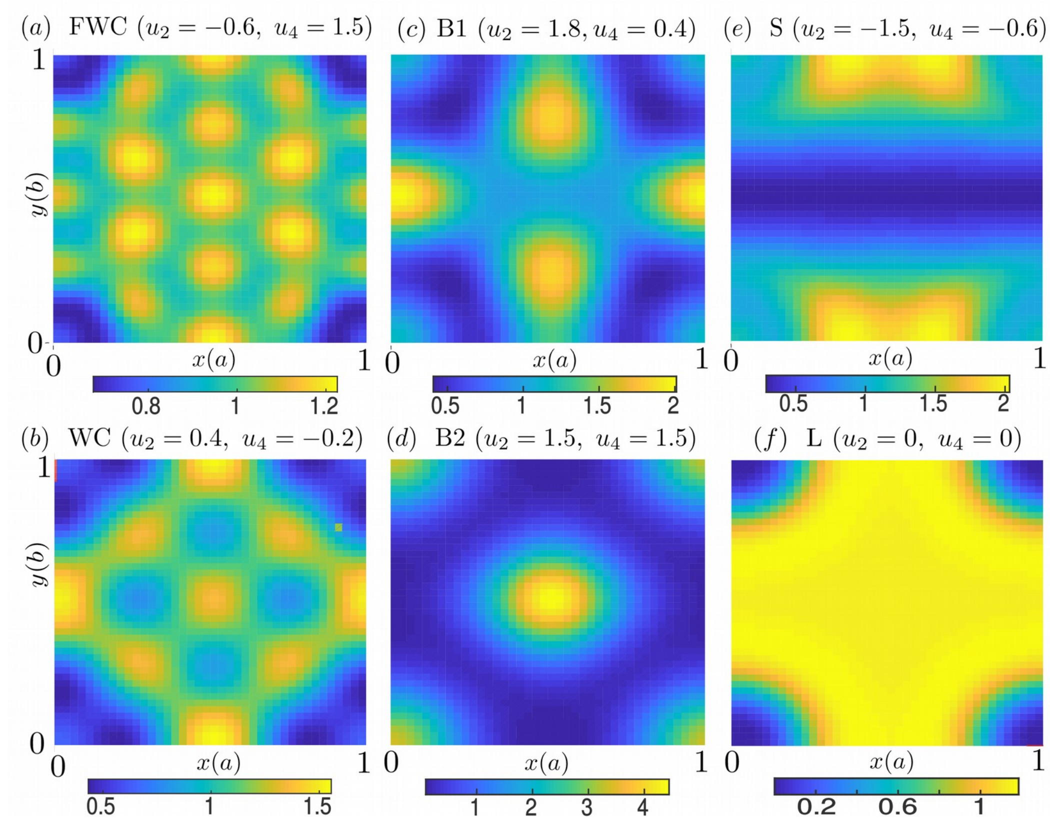
  non-Abelian Fibonacci anyons



Synthetic FQH matter: opportunities

- Interparticle interactions tunable via Rydberg dressing.
- Transition of Laughlin liquid into symmetry-broken phases:





[TG, Bienias, Lundgren, Gullans, Maciejko, Gorshkov, Phys. Rev. Lett. 121, 253403 (2018)]

- Fractional Wigner crystal: Exotic combination of topological order and symmetry-broken order?

[Xia, Eisenstein, Pfeiffer, West, Nat. Phys. (2011)]
[Samkharadze, ..., Fradkin, Csáthy, Nat. Phys (2016)]

Electronic FQH matter

- Fractional Quantum Hall physics in synthetic matter:

  → Engineering of Hamiltonian

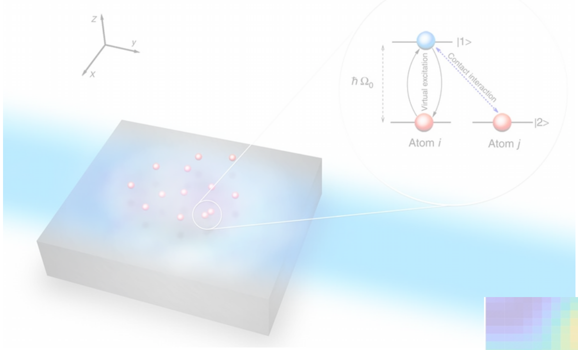
  Synthetic gauge fields

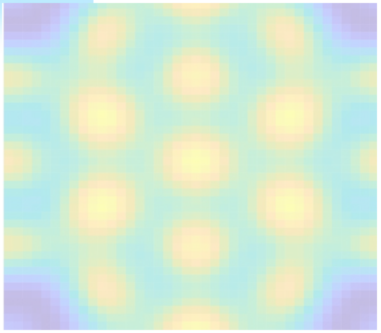
  → Preparation of ground state

  Adiabatic scheme

  → Reward of these efforts:

  - enhanced detection opportunities (anyon detection)
  - engineering of exotic phases (fractional Wigner crystal)





- Fractional Quantum Hall physics in electronic matter:

  → Monolayer graphene in *B* field:

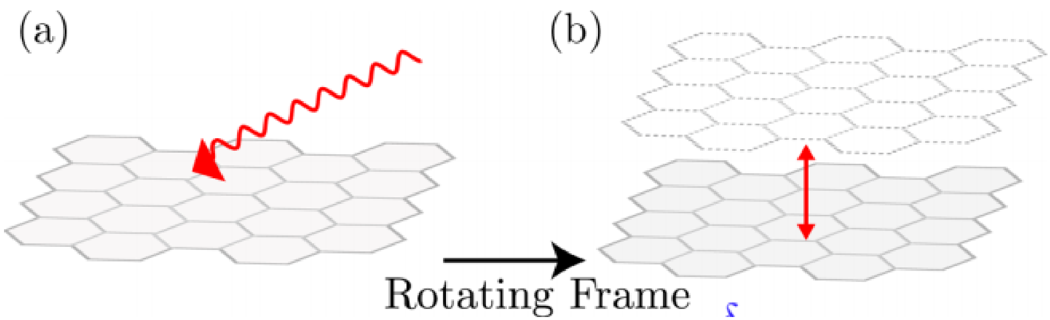
  Laughlin state

  → Optical driving:

  synthetic bilayer structure

  → Reward:

  non-Abelian Fibonacci anyons



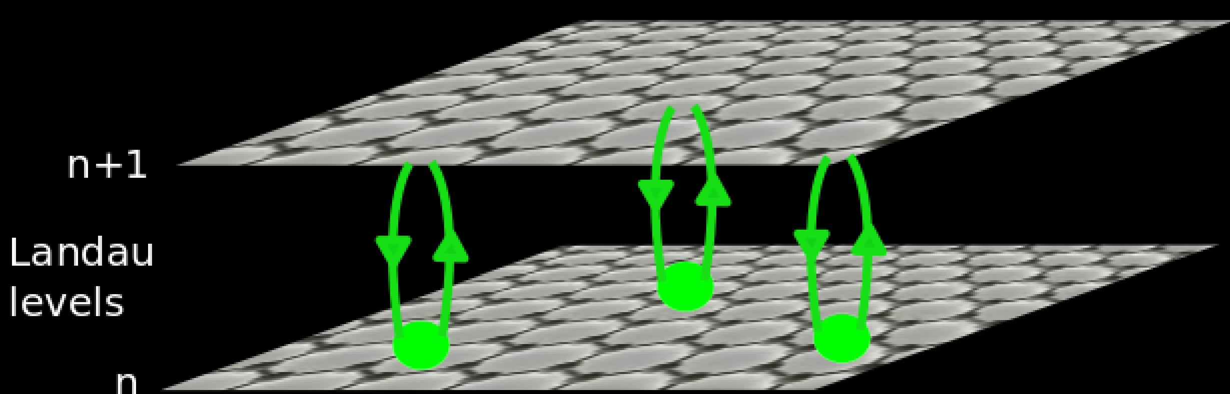
Optical driving in graphene

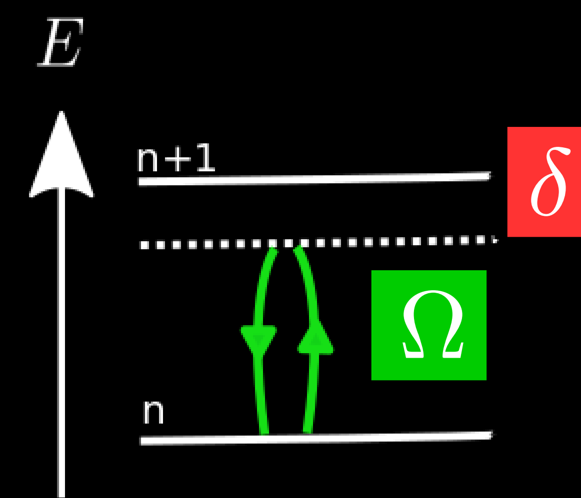
Optical engineering of electronic Hamiltonians:

- Floquet topological insulator in graphene
- Breaking of time-reversal symmetry through circularly polarized or twisted light

[Oka & Aoki, PRB (2009)]
[McIver, ..., Cavalleri, Nat. Phys. (2020)]
[Bhattacharya, Chaudhary, TG, Lewenstein arXiv:2006.10688]

In quantum Hall regime: Optically coupled Landau levels form synthetic bilayer.





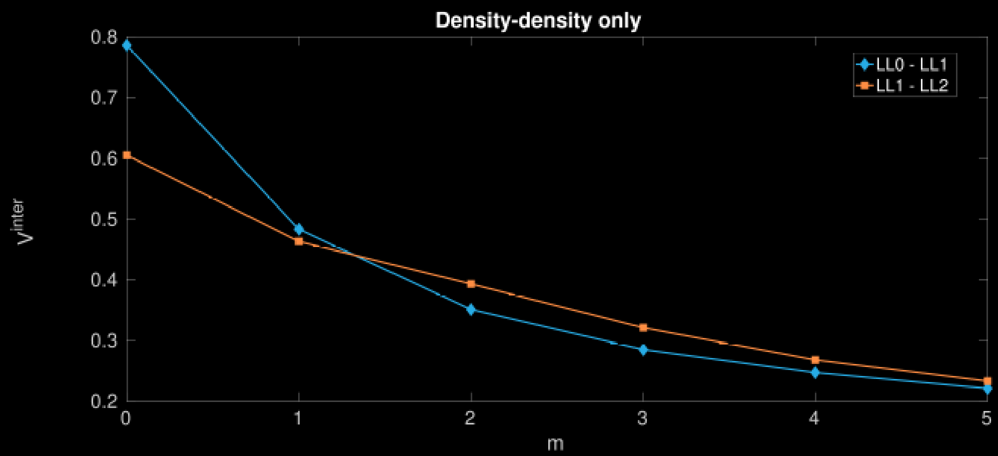
$$H_0 = \sum_m \left[\hbar\delta c^\dagger_{n+1,m} c_{n+1,m} + \hbar\Omega c^\dagger_{n+1,m} c_{n,m} \right] + \text{h.c.}$$

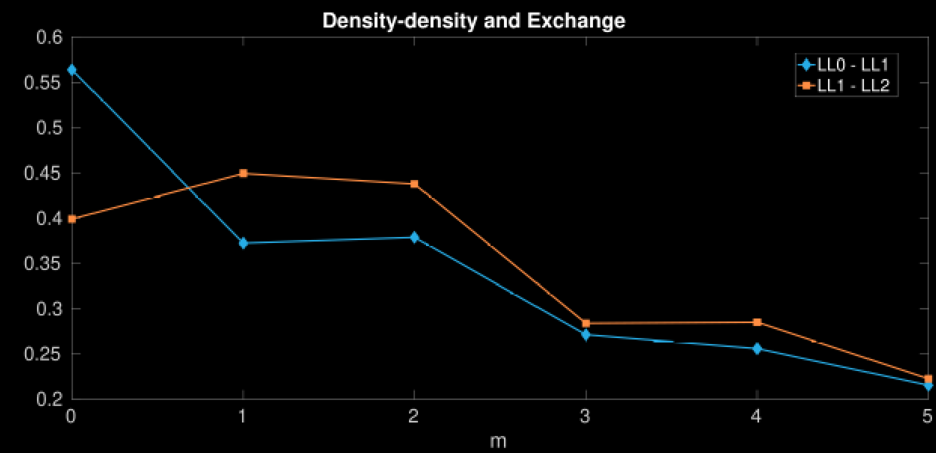
"chemical potential" "interlayer tunneling"

[Ghazaryan, TG, Gullans, Ghaemi, Hafezi, Phys. Rev. Lett. 119, 247403 (2017)]

Exotic interactions and Fibonacci phase

Synthetic bilayer exhibits exotic structure of Haldane pseudopotentials:





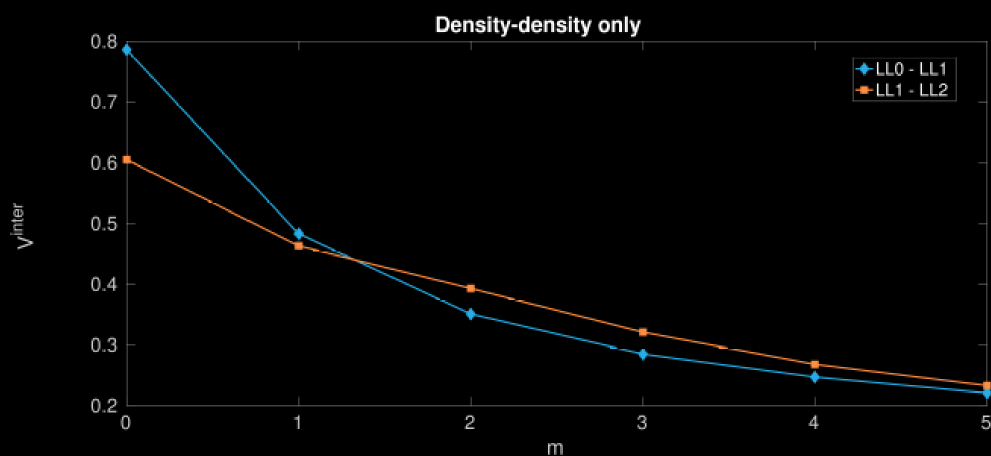
Normal bilayer: Monotonic decay.

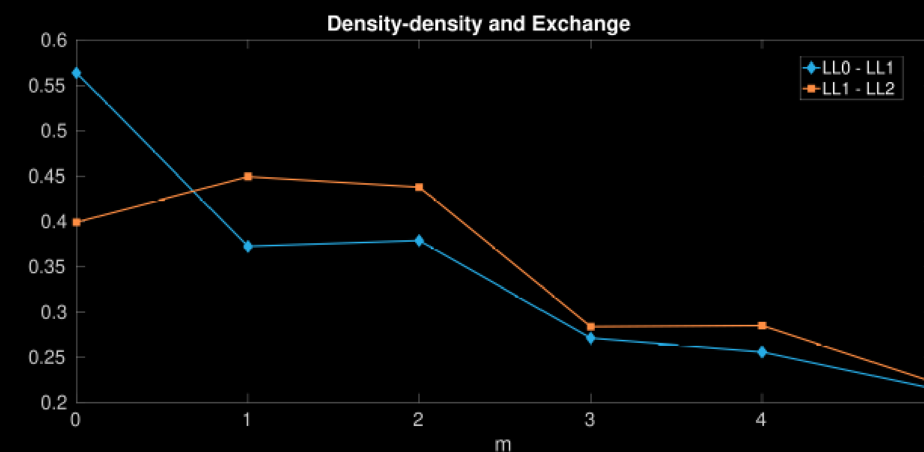
Synthetic bilayer interactions: non-monotonic behavior favoring singlets at m=0

[Cian, TG, Vaezi, Liu, Hafezi, Phys. Rev. B 102, 085430 (2020)]
[Ghazaryan, TG, Gullans, Ghaemi, Hafezi, Phys. Rev. Lett. 119, 247403 (2017)]

Exotic interactions and Fibonacci phase

Synthetic bilayer exhibits exotic structure of Haldane pseudopotentials:





Normal bilayer: Monotonic decay.

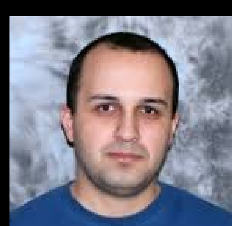
Synthetic bilayer interactions: non-monotonic behavior favoring singlets at m=0

→ Synthetic bilayer supports non-Abelian Fibonacci phase.

(candidate for ***universal*** topological quantum computing)


Mohammad Hafezi (JQI)


Ze-Pei Cian (JQI)

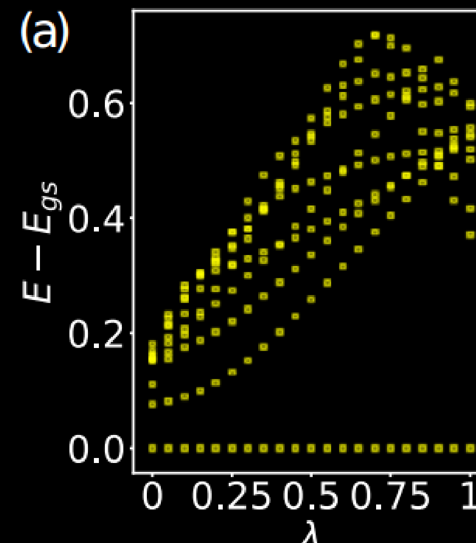

Areg Ghazaryan (IST Austria)


Pouyan Ghaemi (CUNY)


Abolhassan Vaezi (Tehran)


Zhao Liu (Zhejiang)

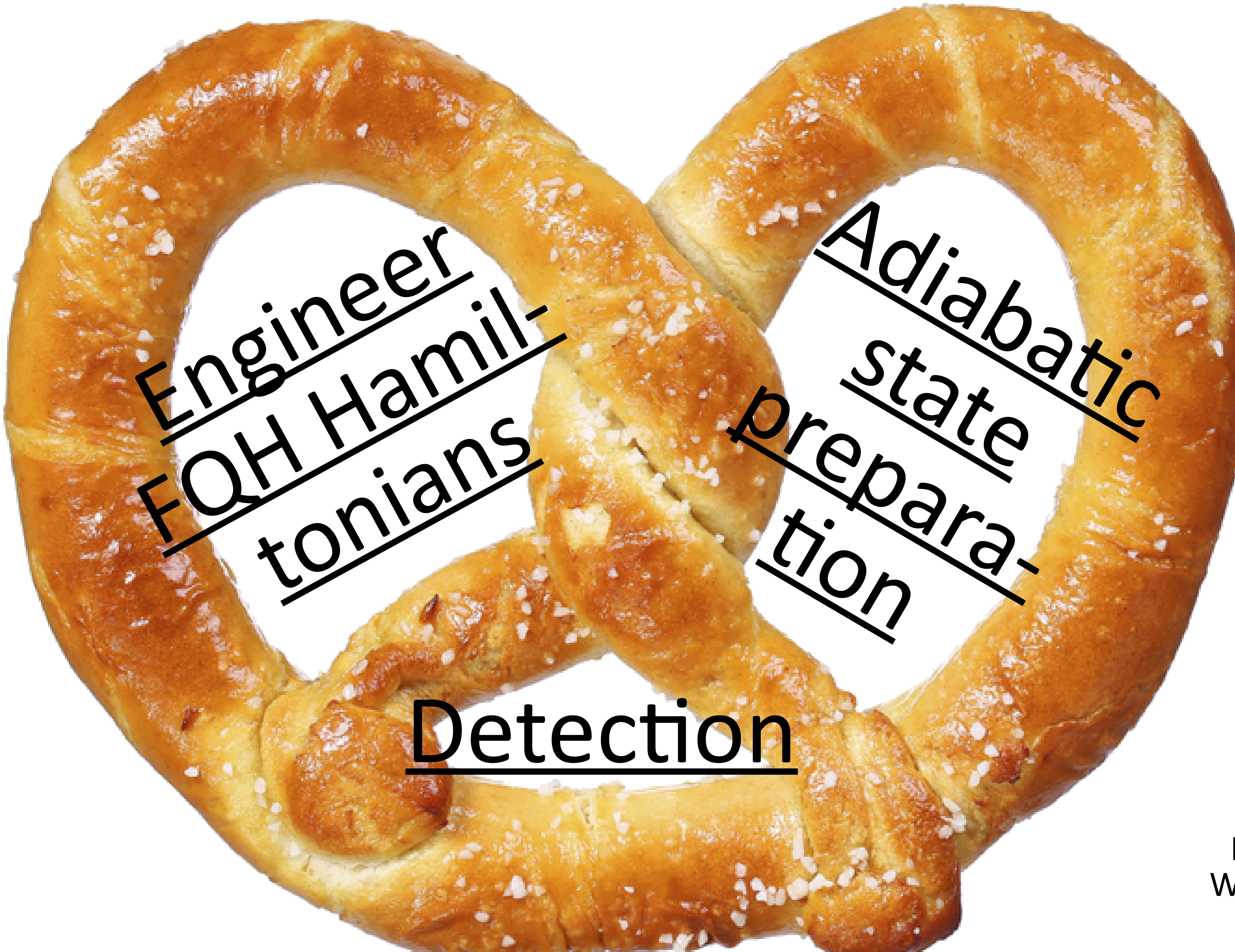
(a)



Adiabatic connection to parent Hamiltonian

[Cian, TG, Vaezi, Liu, Hafezi, Phys. Rev. B 102, 085430 (2020)]
[Ghazaryan, TG, Gullans, Ghaemi, Hafezi, Phys. Rev. Lett. 119, 247403 (2017)]

Thank you!



@ ICFO:
Barbara Andrade
Niccolo Baldelli
Utso Bhattacharya
Alexandre Dauphin
Joana Fraxenet
Valentin Kasper
Bernhard Irsigler
Maciej Lewenstein
Debrah Rakshit
Leticia Tarruell

@ JQI/UMD/NIST:
Przemek Bienias
Bin Cao
Ze-Pei Cian
Alexey Gorshkov
Mohammad Hafezi
Rex Lundgren
Glenn Solomon

Nuria Barberan	(UBarcelona)
Alessio Celi	(UA Barcelona)
Ovidiu Cotlet	(ETH Zurich)
Michael Gullans	(Princeton)
Walter Hofstetter	(U Frankfurt)
Tobias Huber	(U Wuerzburg)
Atac Imamoglu	(ETH Zurich)
Bruno Julia-Diaz	(UBarcelona)
Joseph Maciejko	(Alberta)
Guido Pagano	(RICE)
David Raventos	(IFF Madrid)
Christoph Weitenberg	(U Hamburg)
Abolhassan Vaezi	(Sharif)

Fundación "la Caixa"
Generalitat de Catalunya
Fundació Privada CELLEX
Fundació Privada MIR-PUIG
Ministerio de Economía, Industria y Competitividad
Excelencia Severo Ochoa
NSF

Max-Planck Institute for the Science of Light

11.03.2021

Discussion of Plans

Designer Quantum Matter from the Optical Toolbox and more

Tobias Grass

ICFO

Fundación "la Caixa" · Generalitat de Catalunya · Fundació Privada CELLEX · Fundació Privada MIR-PUIG · Ministerio de Economía, Industria y Competitividad · Excelencia Severo Ochoa · NSF

Research lines

CONDENSED MATTER THEORY MEETS QUANTUM OPTICS

- Floquet Engineering of Many-Body Phases
- Non-linear optics and strongly correlated matter

QUANTUM INFORMATION

- Quantum Algorithms and Machine Learning
- Topological Codes

New Quantum Simulation Platforms

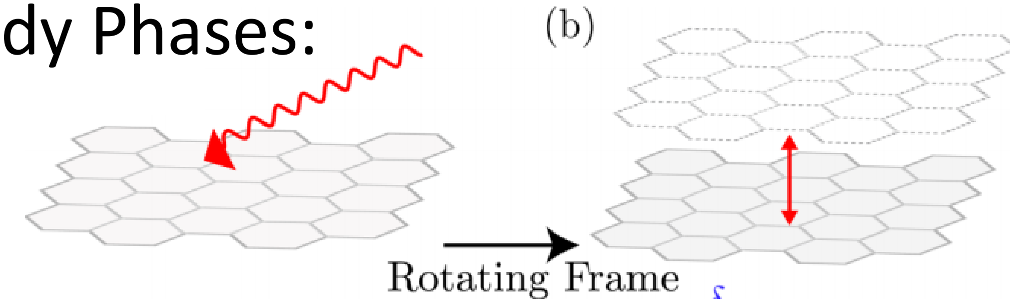
Quantum Materials “on demand”

Detection of Topological Properties

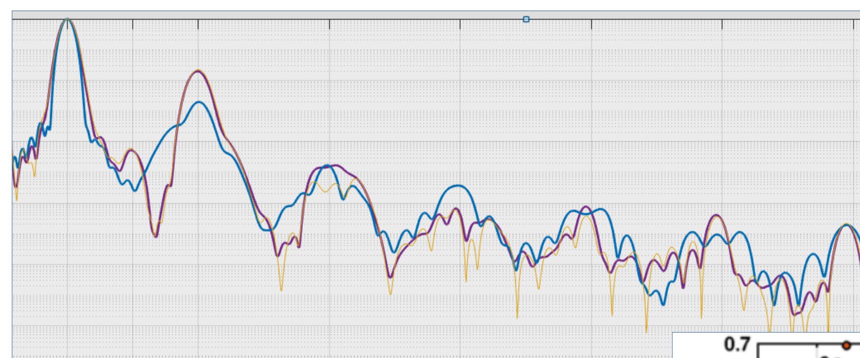
Software for Quantum Computers

List of Topics

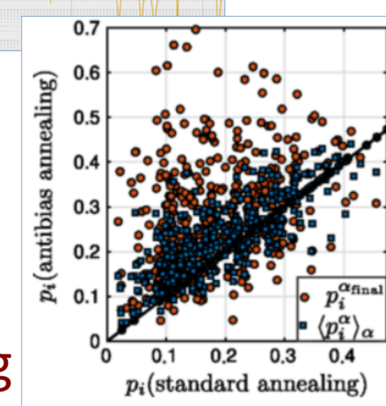
- Floquet Engineering of Many-Body Phases:
  - Optical dressing: tunable interactions for electrons
  - *N*-body interactions?
  - The heating challenge: Tailoring thermalization channels?
  - More structure using structured light: electronic quantum simulators?



- Non-linear optics and strongly correlated matter:
  - High-harmonic spectra from topological matter
  - Exciton-polaritons in topological matter and topological matter out of exciton-polaritons



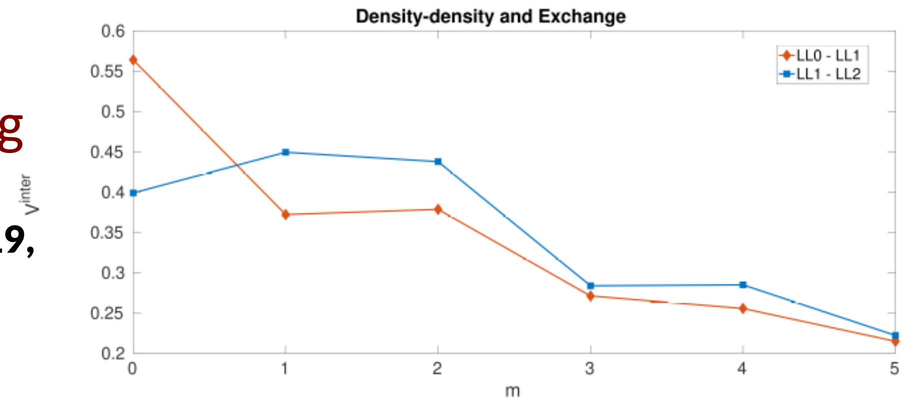
- Quantum Algorithms:
  - Digital gate preparation of topological states
  - Checks and cheats for adiabatic quantum computers
  - Understand computational complexity using machine learning

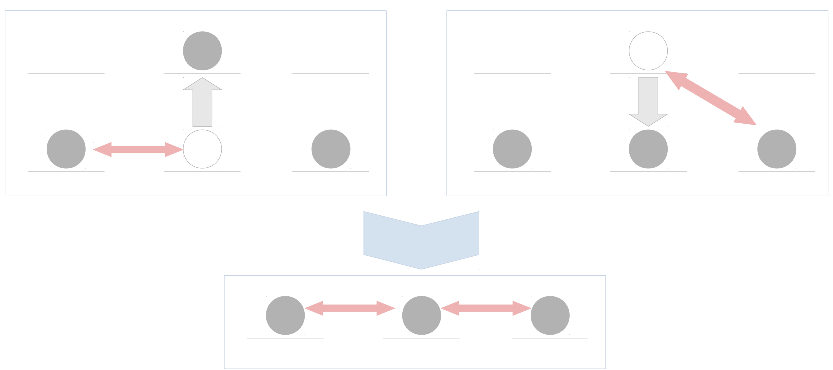


Floquet Engineering of Many-Body Phases

- Tunable Interactions:
  - Coupled Landau levels yields synthetic bilayer with exotic interactions - depending on coupled levels
    [Ghazaryan, TG, Gullans, Ghaemi, Hafezi, Phys. Rev. Lett. 119, 247403 (2017)]
  - Develop systematic coupling scheme (various LLs , pulse shaping, etc.) for interactions "on demand"
  - LL mixing leads to effective *N*-body interactions
    [Sodemann & MacDonald, Phys. Rev. B 87, 245425 (2013)]

    Even weak terms are relevant in some systems (e.g. 5/2 state)
    [Pakrouski, Peterson, Jolicoeur, Scarola, Nayak, Troyer, Phys. Rev. X 5, 021004 (2015)]

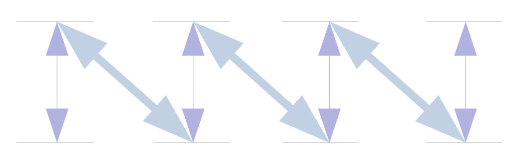




[Seetharam *et al.*, Phys. Rev. X 5, 041050 (2015)]

[D'Alessio & Rigol, Phys. Rev. X 4, 041048 (2014)]

- Heating is bottleneck of Floquet engineering. Include thermalization!
  - Simulate open system dynamics (e.g. quantum jump method)
- Further topics: SSH model, twisted bilayer, twisted light,...

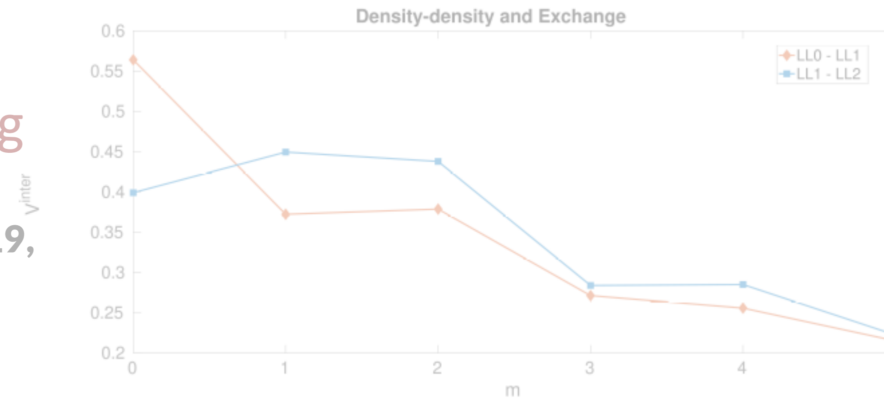


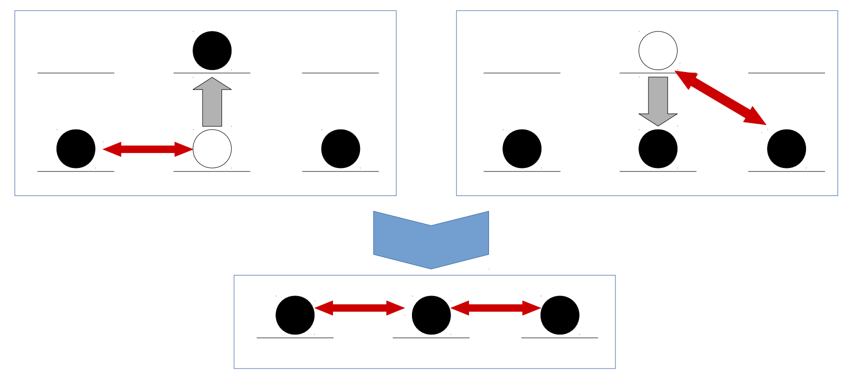
Topology in topology: Coupled Landau levels form SSH chain.

Floquet Engineering of Many-Body Phases

- Tunable Interactions:
  - Coupled Landau levels yields synthetic bilayer with exotic interactions - depending on coupled levels
    [Ghazaryan, TG, Gullans, Ghaemi, Hafezi, Phys. Rev. Lett. 119, 247403 (2017)]
  - Develop systematic coupling scheme (various LLs , pulse shaping, etc.) for interactions "on demand"
  - LL mixing leads to effective *N*-body interactions
    [Sodemann & MacDonald, Phys. Rev. B 87, 245425 (2013)]

    Even weak terms are relevant in some systems (e.g. 5/2 state)
    [Pakrouski, Peterson, Jolicoeur, Scarola, Nayak, Troyer, Phys. Rev. X 5, 021004 (2015)]

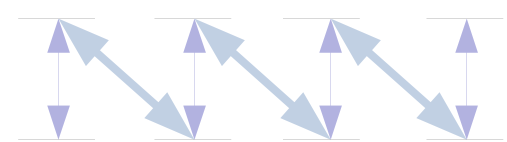




- Heating is bottleneck of Floquet engineering. Include thermalization!
  - Simulate open system dynamics (e.g. quantum jump method)

[Seetharam *et al.*, Phys. Rev. X 5, 041050 (2015)]

[D'Alessio & Rigol, Phys. Rev. X 4, 041048 (2014)]



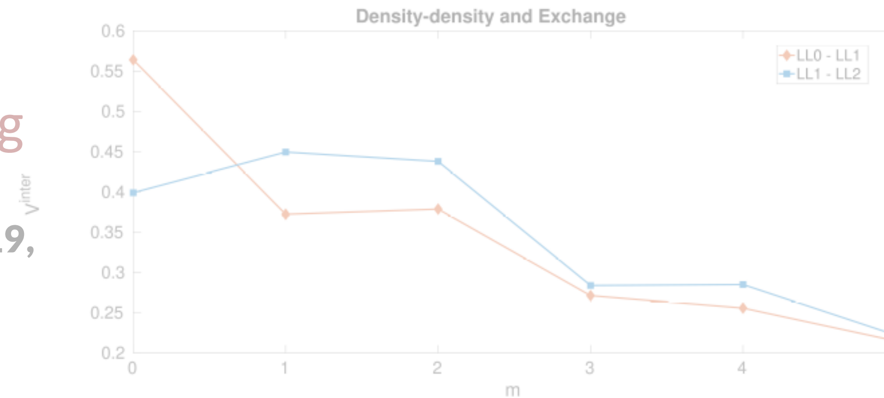
Topology in topology: Coupled Landau levels form SSH chain.

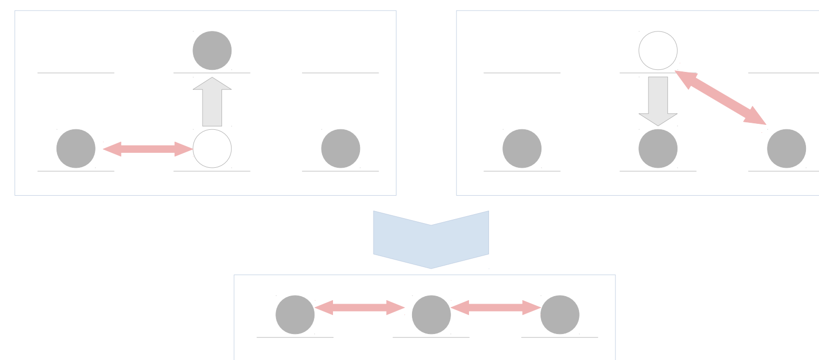
- Further topics: SSH model, twisted bilayer, twisted light,...

Floquet Engineering of Many-Body Phases

- Tunable Interactions:
  - Coupled Landau levels yields synthetic bilayer with exotic interactions - depending on coupled levels
    [Ghazaryan, TG, Gullans, Ghaemi, Hafezi, Phys. Rev. Lett. 119, 247403 (2017)]
  - Develop systematic coupling scheme (various LLs , pulse shaping, etc.) for interactions "on demand"
  - LL mixing leads to effective *N*-body interactions
    [Sodemann & MacDonald, Phys. Rev. B 87, 245425 (2013)]

    Even weak terms are relevant in some systems (e.g. 5/2 state)
    [Pakrouski, Peterson, Jolicoeur, Scarola, Nayak, Troyer, Phys. Rev. X 5, 021004 (2015)]



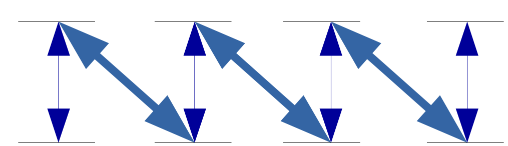


- Heating is bottleneck of Floquet engineering. Include thermalization!
  - Simulate open system dynamics (e.g. quantum jump method)

[Seetharam *et al.*, Phys. Rev. X 5, 041050 (2015)]

[D'Alessio & Rigol, Phys. Rev. X 4, 041048 (2014)]

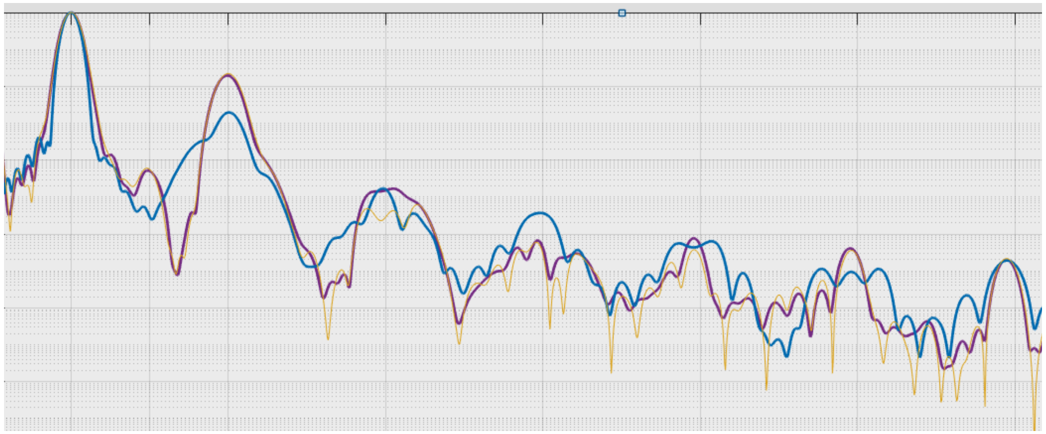
- Further topics: SSH model, twisted bilayer, twisted light,...

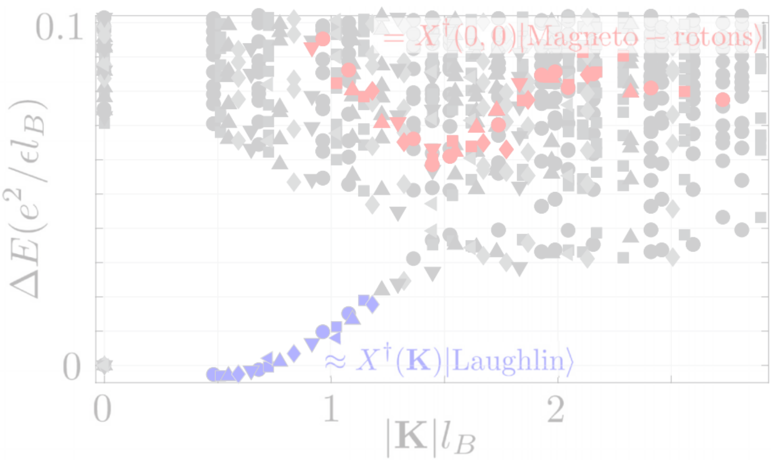


Topology in topology: Coupled Landau levels form SSH chain.

Non-linear Optics meets Correlated Matter

- High-harmonic generation
  - Well established in atomic systems, getting "popular" also in condensed matter
    [Ghimire and Reis, Nat. Phys. 15, 10 (2019)]
  - Detection of topology via HHG
    [A. Chacon *et al.*, Phys. Rev. B 102, 134115 (2020)]
  - Signatures of anyons?
    - Kitaev chain (quadratic model)
    - Interacting models
  - Signature of superconductivity?
    - HHG spectra of cuprates
    - Light-induced superconductivity





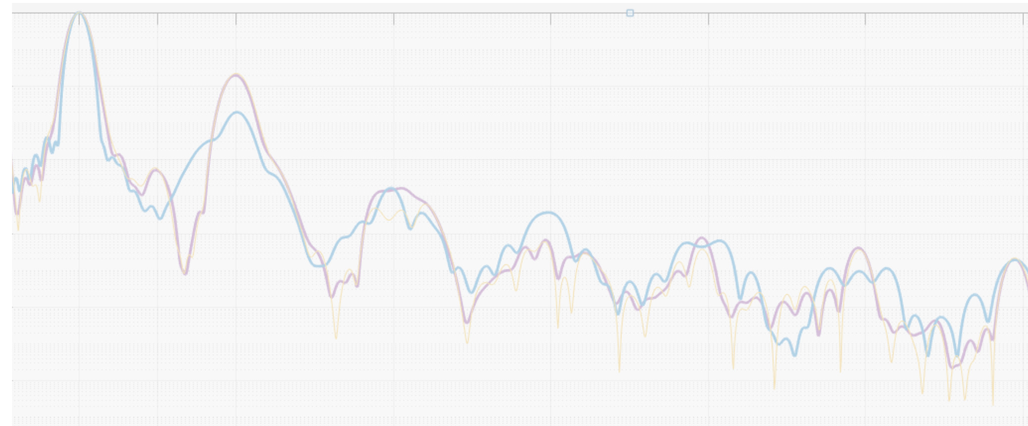
- Excitonic systems
  - Exciton-polaritons in FQH systems – theoretical model for interactions?
  - Excitons bound to quasiparticles: Anyon detection via impurities?
  - Many-body phases of excitons: strong interactions, artificial gauge fields,…?

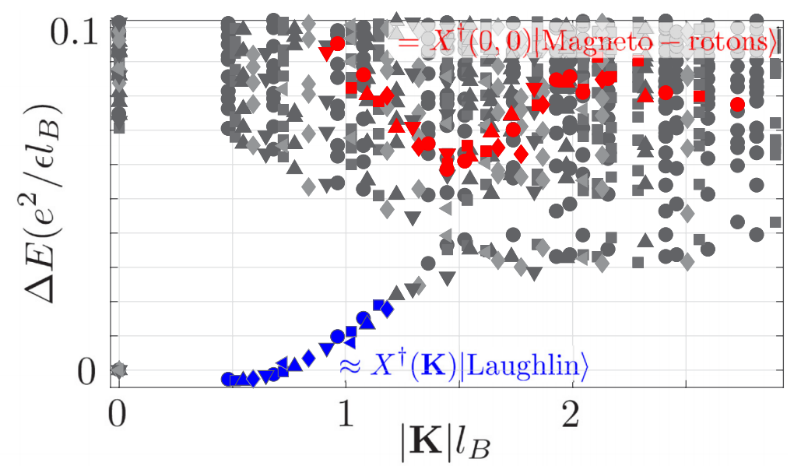
[S. Ravets *et al.*, Phys. Rev. Lett. 120, 057401 (2018)]
[TG, Cotlet, İmamoğlu, Hafezi, Phys. Rev. B 101, 155127 (2020)]

[Kwon *et al.*, Phys. Rev. Lett. 122, 045302 (2019)]
[Sanvitto *et al.*, Nat. Phys. 6, 527 (2010)]
[Lackner, ..., Hoefling, Schneider, arXiv 2102.09565]

Non-linear Optics meets Correlated Matter

- High-harmonic generation
  - Well established in atomic systems, getting “popular” also in condensed matter
    [Ghimire and Reis, Nat. Phys. 15, 10 (2019)]
  - Detection of topology via HHG
    [A. Chacon *et al.*, Phys. Rev. B 102, 134115 (2020)]
  - Signatures of anyons?
    - Kitaev chain (quadratic model)
    - Interacting models
  - Signature of superconductivity?
    - HHG spectra of cuprates
    - Light-induced superconductivity





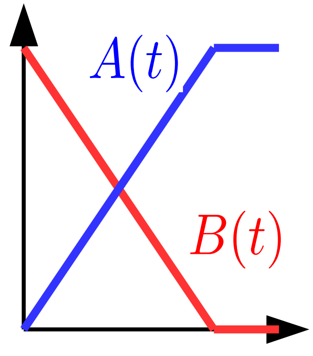
- Excitonic systems
  - Exciton-polaritons in FQH systems – theoretical model for interactions?
  - Excitons bound to quasiparticles: Anyon detection via impurities?
  - Many-body phases of excitons: strong interactions, artificial gauge fields,…?

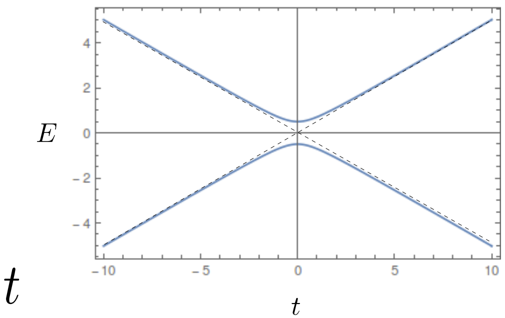
[S. Ravets *et al.*, Phys. Rev. Lett. 120, 057401 (2018)]
[TG, Cotlet, İmamoğlu, Hafezi, Phys. Rev. B 101, 155127 (2020)]

[Kwon *et al.*, Phys. Rev. Lett. 122, 045302 (2019)]
[Sanvitto *et al.*, Nat. Phys. 6, 527 (2010)]
[Lackner, …, Hoefling, Schneider, arXiv 2102.09565]

Quantum Algorithms

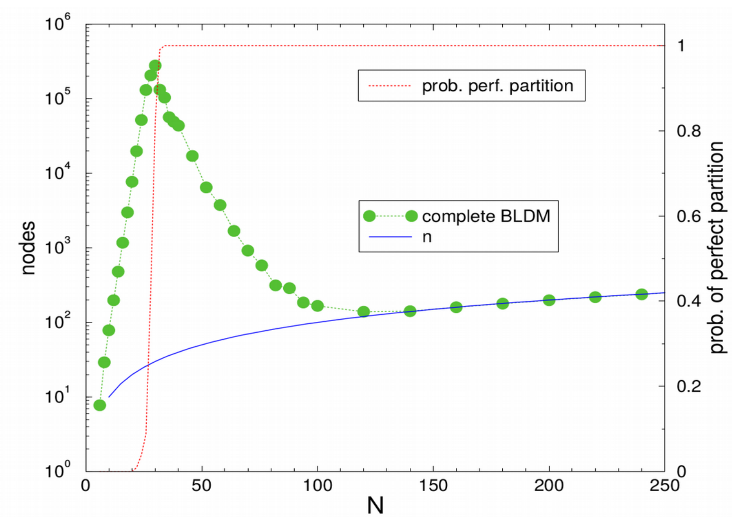
- Quantum Annealing
  - Bottleneck: Closing of gap
    [Altshuler, Krovi, Roland, PNAS 107 12446 (2010)]
  - Bias field can lead to significant improvements
    [TG, Phys. Rev. Lett. 123, 120501 (2019)]
  - Dynamical phase transitions: Hints for critical field strength through quench experiments?
  - Reinforcement learning?
    [Bukov *et al.*, Phys. Rev. X 8, 031086 (2018)]
    [Foesel *et al.*, Phys. Rev. X 8, 031084 (2018)]



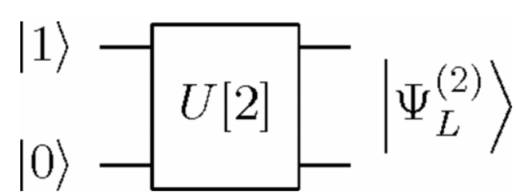


$$H(t) = A(t)H_{\text{problem}} + B(t)H_{\text{driver}}$$

- Understanding computational complexity
  - Phase transitions of computational complexity
    [Mertens, Phys. Rev. Lett. 81, 4281 (1998)]
  - Expectation: There are more subtle patterns which characterize the hard instances
  - Idea: Use machine learning to identify them.



- Gate preparation of topological qubits
  [J. I. Latorre, V. Picó, and A. Riera Phys. Rev. A 81, 060309 (2010)]
  [Rahmani *et al.* PRX QUANTUM 1, 020309 (2020)]

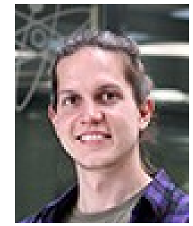


My group

- Currently: 2 PhD students 1 Post-Doc

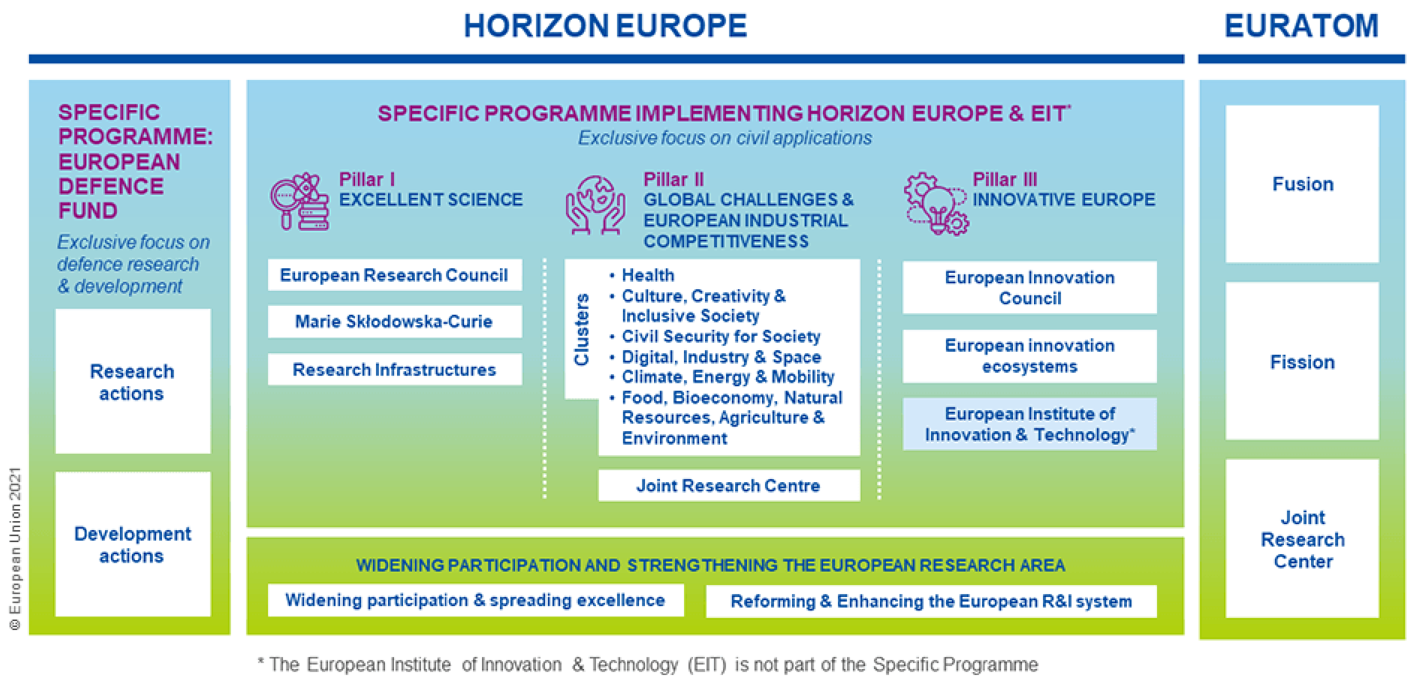
Nicollo Baldelli
since 2019

Barbara Andrade
since 2020



Bernhard Irsigler
since 2021

- Next steps:
  - Local students?
  - New hires?
  - Funding?



- Network:

Lewenstein, Chang, Biegert, Bachtold, Tarruell, Wall...
Julia-Diaz, Barberan, Celi, ...

Hafezi, Gorshkov, Solomon, Davoudi,...

Weitenberg, Sengstock

Pagano

Imamoglu