Realizing Fractional Chern Insulators in Dipolar Spin Systems

(or What are quantum computers good at?)

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DOE CSGF Annual Conference

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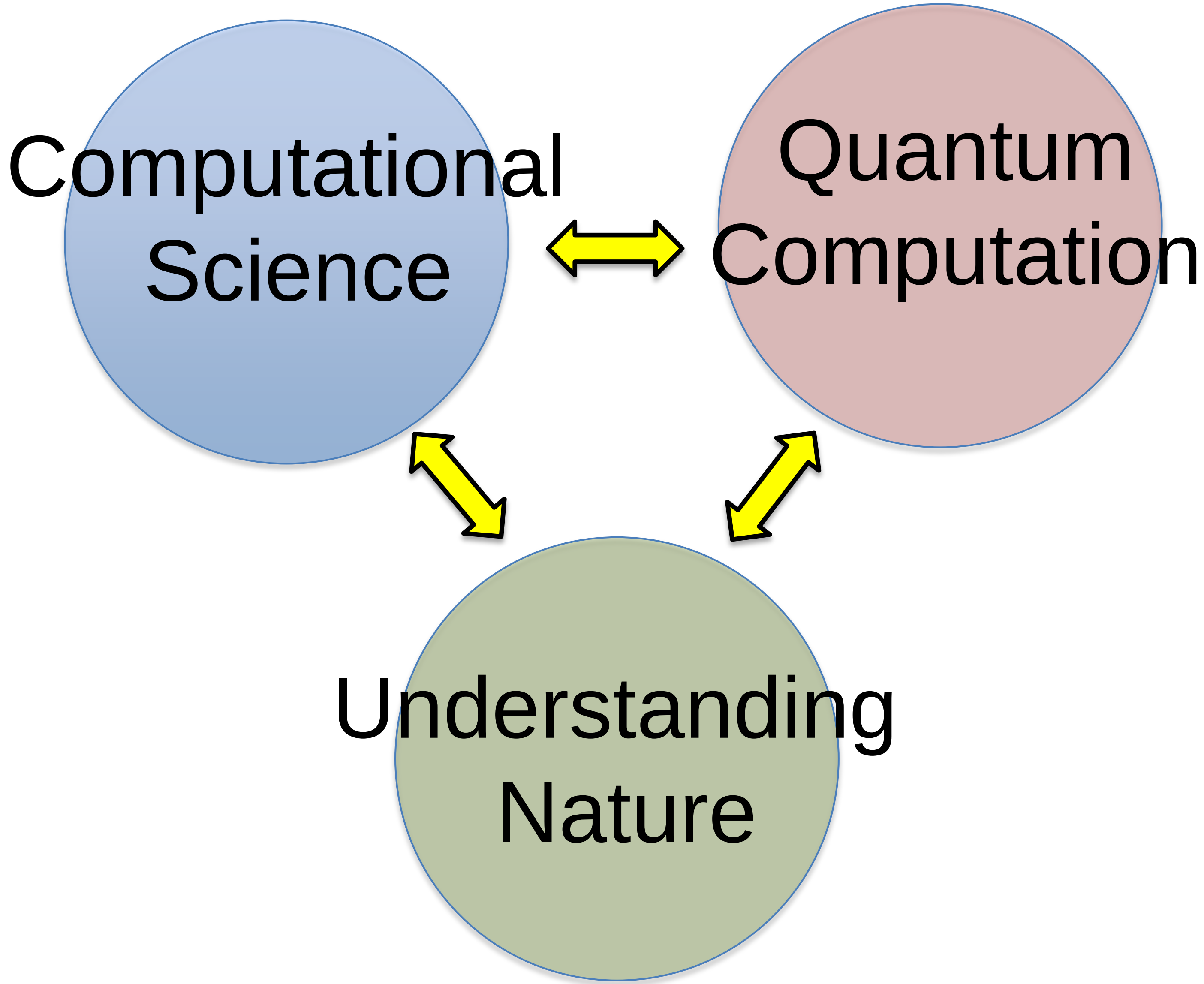
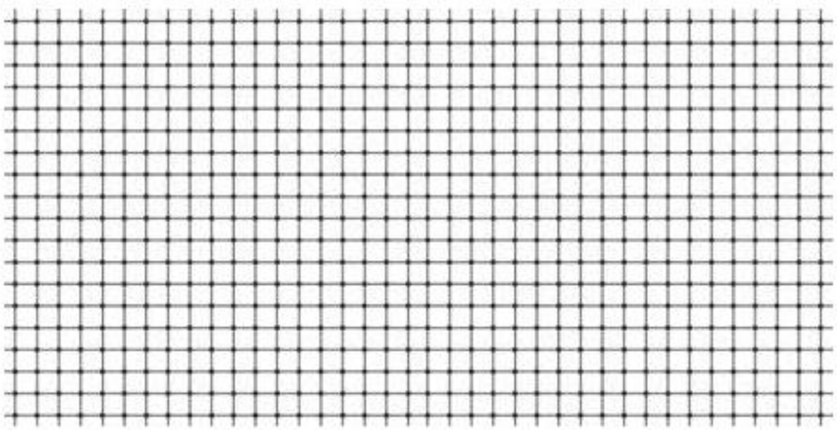

Computational
Science
Quantum
Computation
Understanding
Nature

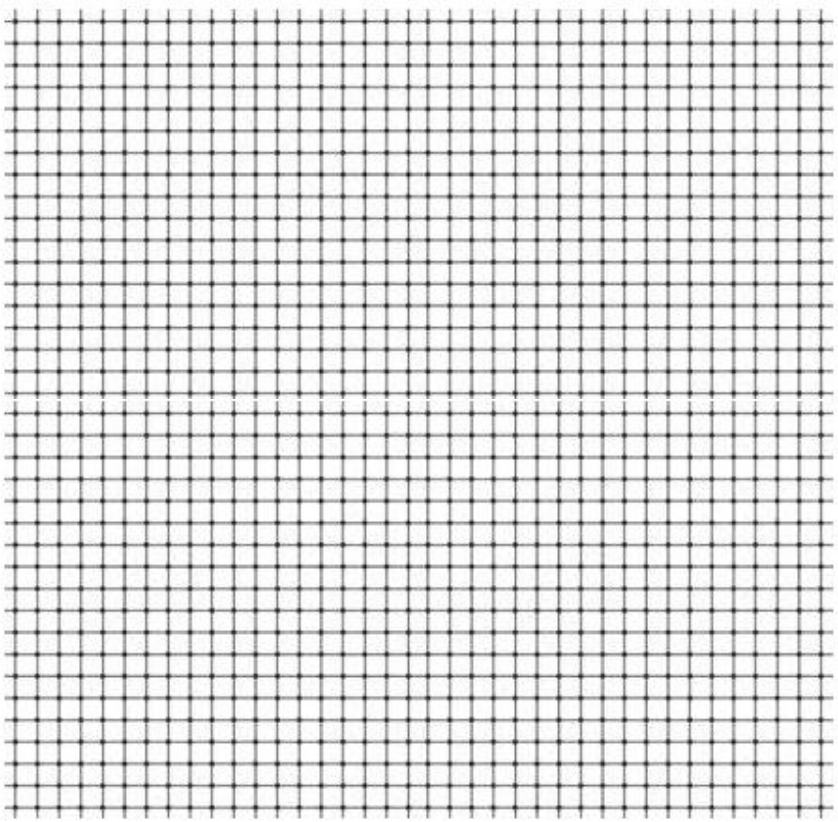
Computational Science: Complexity

* Use computational techniques to solve problems



Computational Science: Complexity

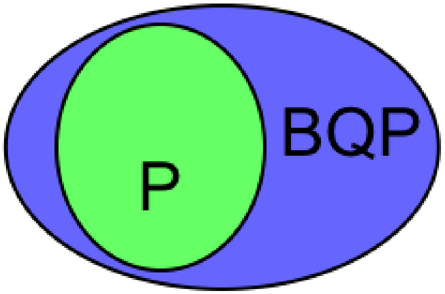
* Use computational techniques to solve problems



Computational Science: Complexity

Complexity theory classifies problems according to the scaling of the resources a computer requires to solve large instances

- P -- solvable in polynomial time by a classical computer
- BQP -- solvable in polynomial time by a quantum computer



P and BQP

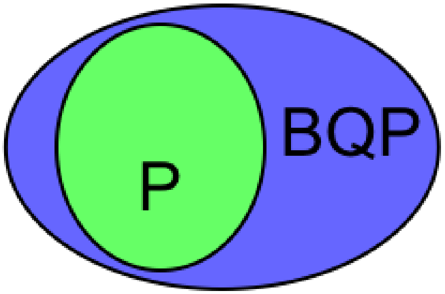
Can identify efficiently solvable (easy!) problems directly: find polynomial time algorithms

- Classical (P):
  - Addition, Multiplication, Sorting Lists

Arithmetic ~500AD

- Quantum (BQP):
  - Is there a factor $1 < p < m$ of the integer N?

Shor 1994

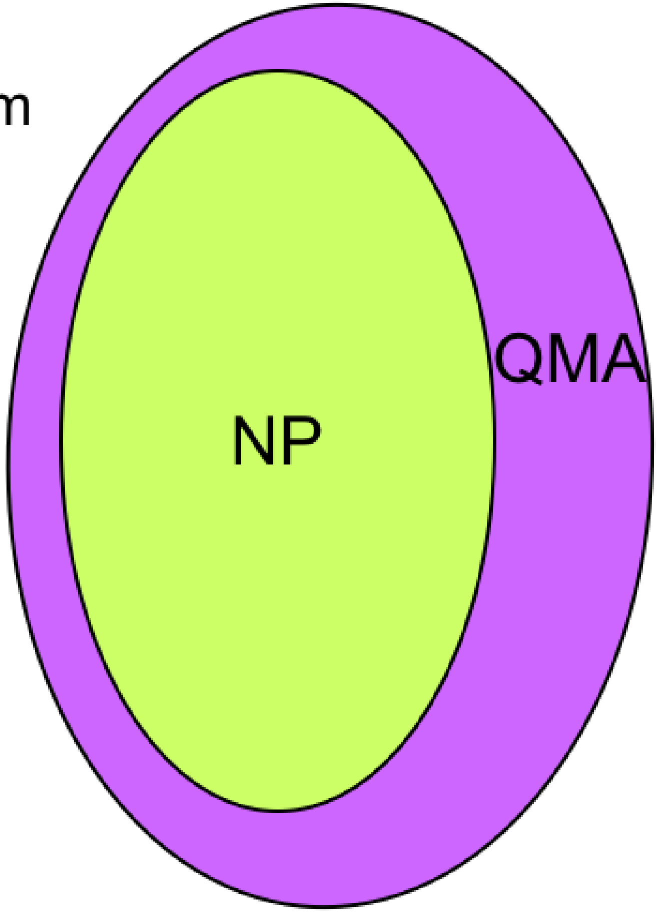


NP and QMA

Identify reasonable problems by finding polynomial times algorithms to check them

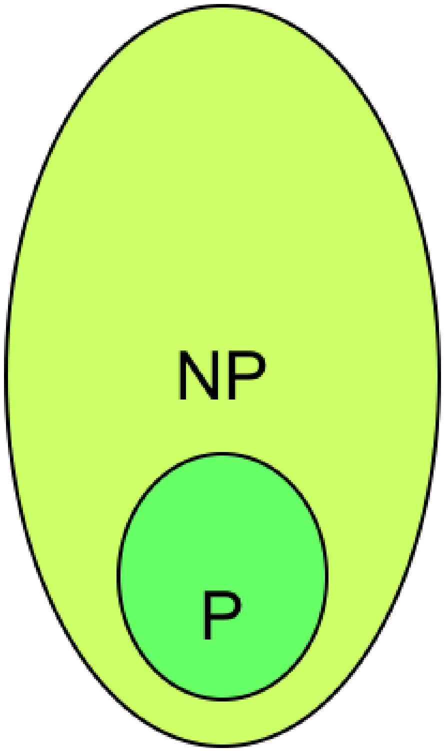
- NP -- checkable in poly time by a classical computer
  - Traveling salesman problem
- QMA -- checkable in poly time by a quantum computer
  - Is the ground state energy of a local Hamiltonian below E?

Kitaev 2001



P$\neq$NP

There are hard problems.*

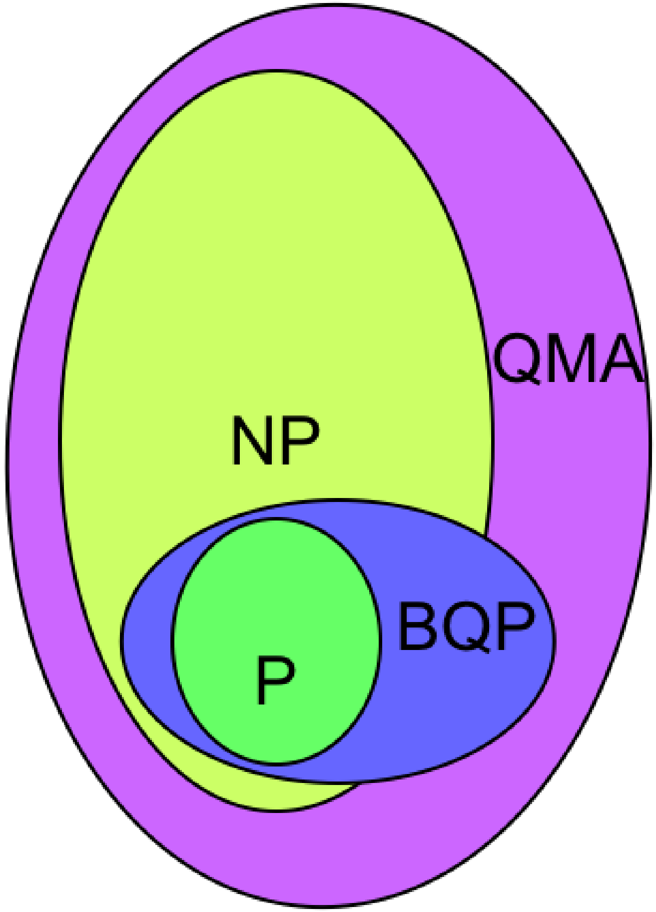


* Conjecture

P≠NP

There are hard problems.*

(even with quantum computers)

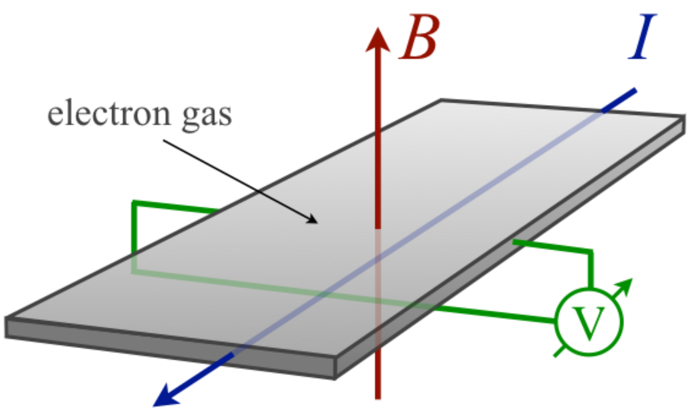


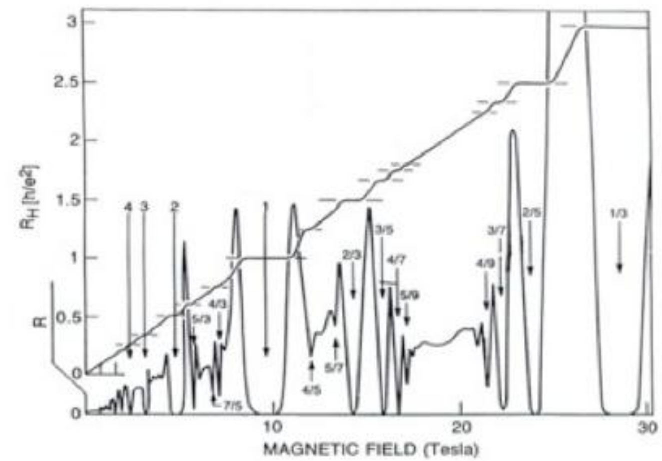
* Conjecture

Quantum Simulation

* Use quantum computer to simulate real-world quantum systems

Fractional Quantum Hall Effect





Klaus V. Klitzing

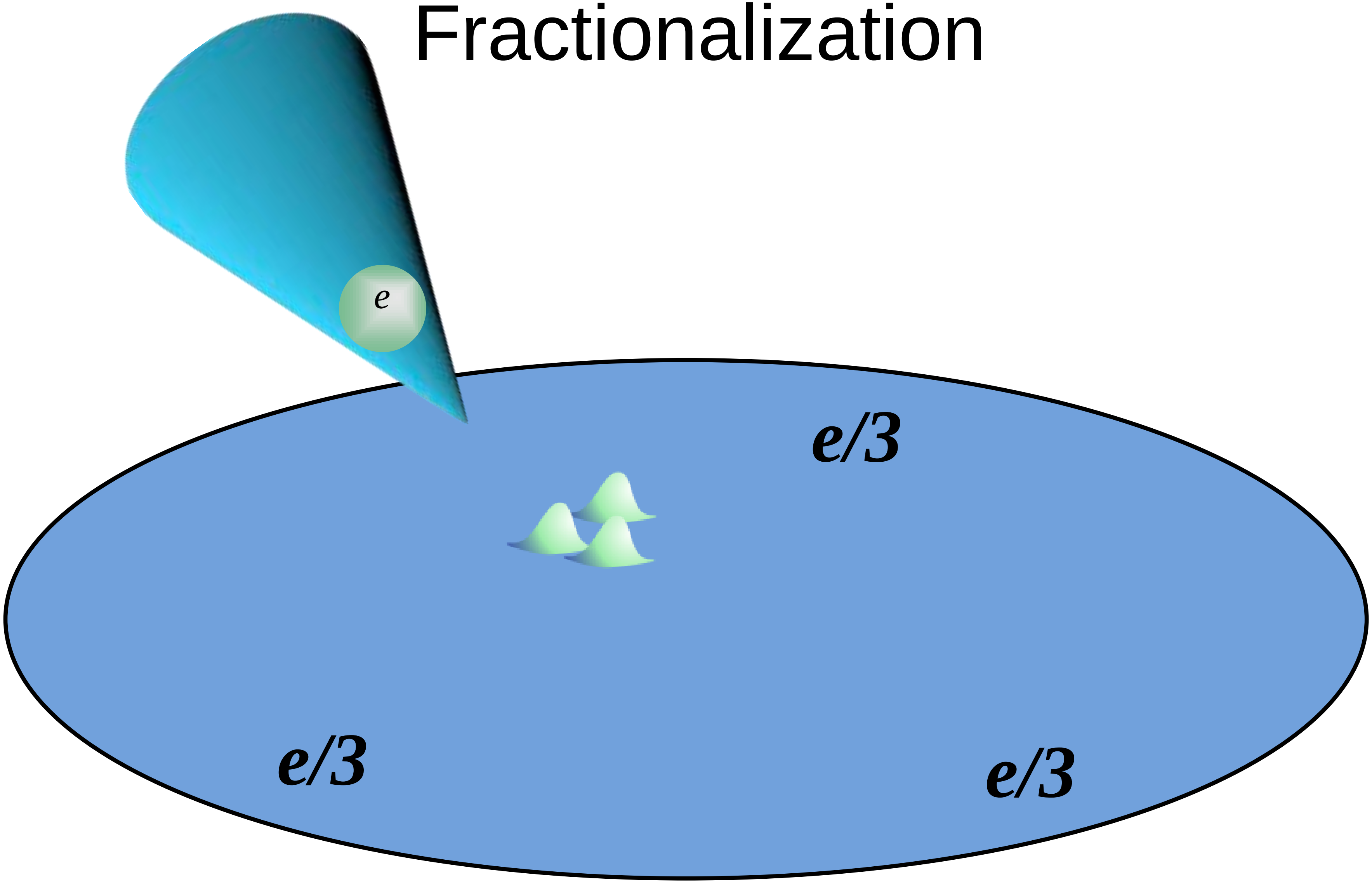
Robert Laughlin

Horst Stormer

Daniel Tsui

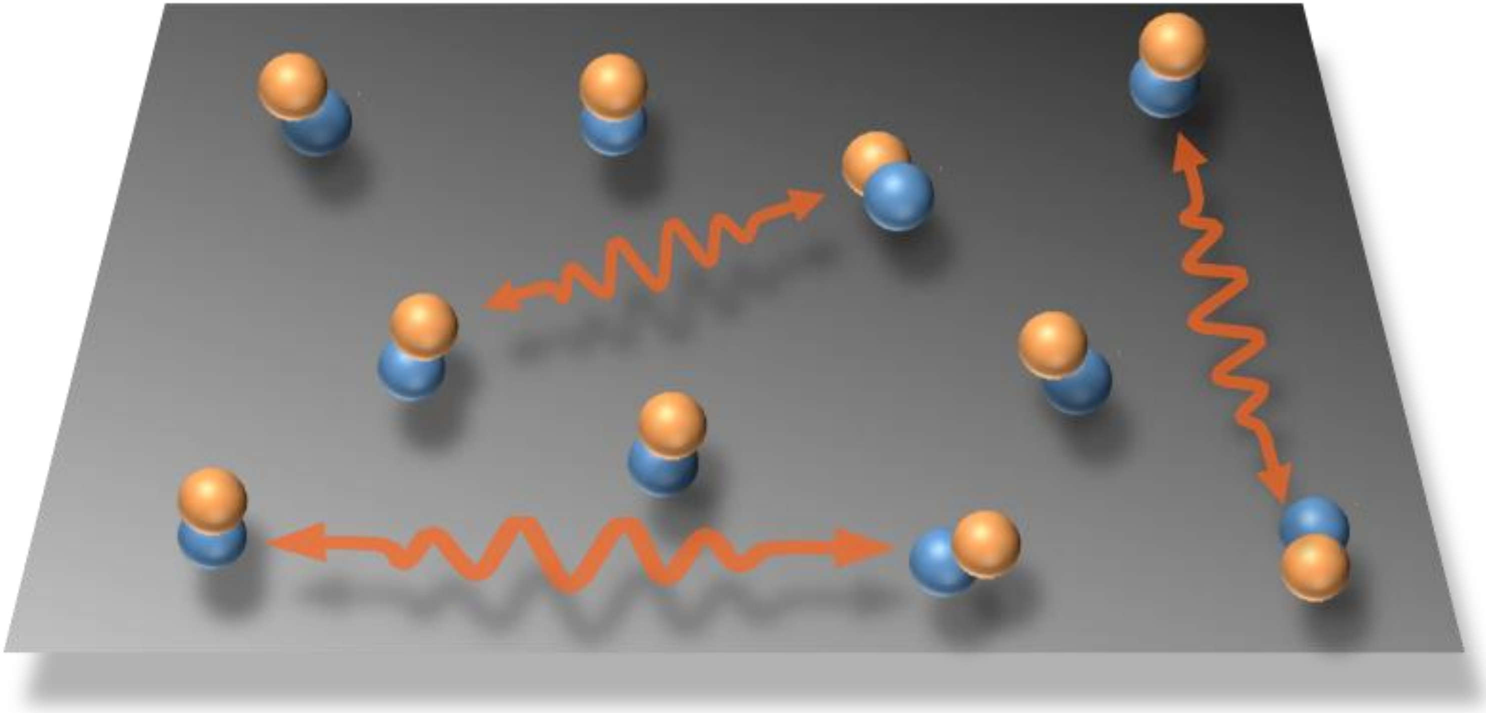
1) **Electrons**
2) **Strong Magnetic Field**

Fractionalization



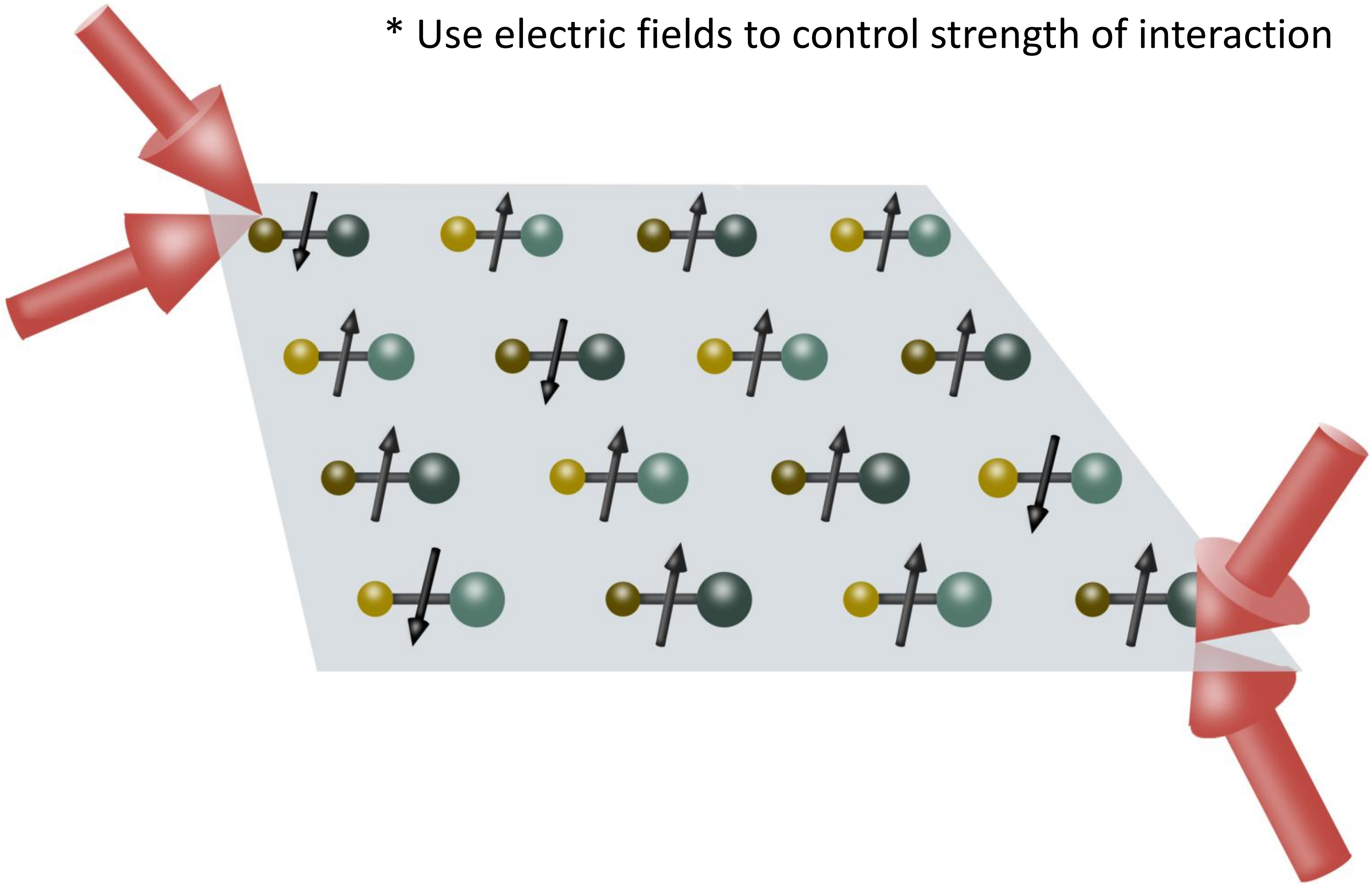
Quantum Simulator of Molecules

$$H_{dd} = \frac{1}{2} \sum_{i \neq j} \frac{\kappa}{R_{ij}^3} \left[\mathbf{d_i} \cdot \mathbf{d_j} - 3(\mathbf{d_i} \cdot \hat{\mathbf{R}}_{\mathbf{ij}})(\mathbf{d_j} \cdot \hat{\mathbf{R}}_{\mathbf{ij}}) \right]$$

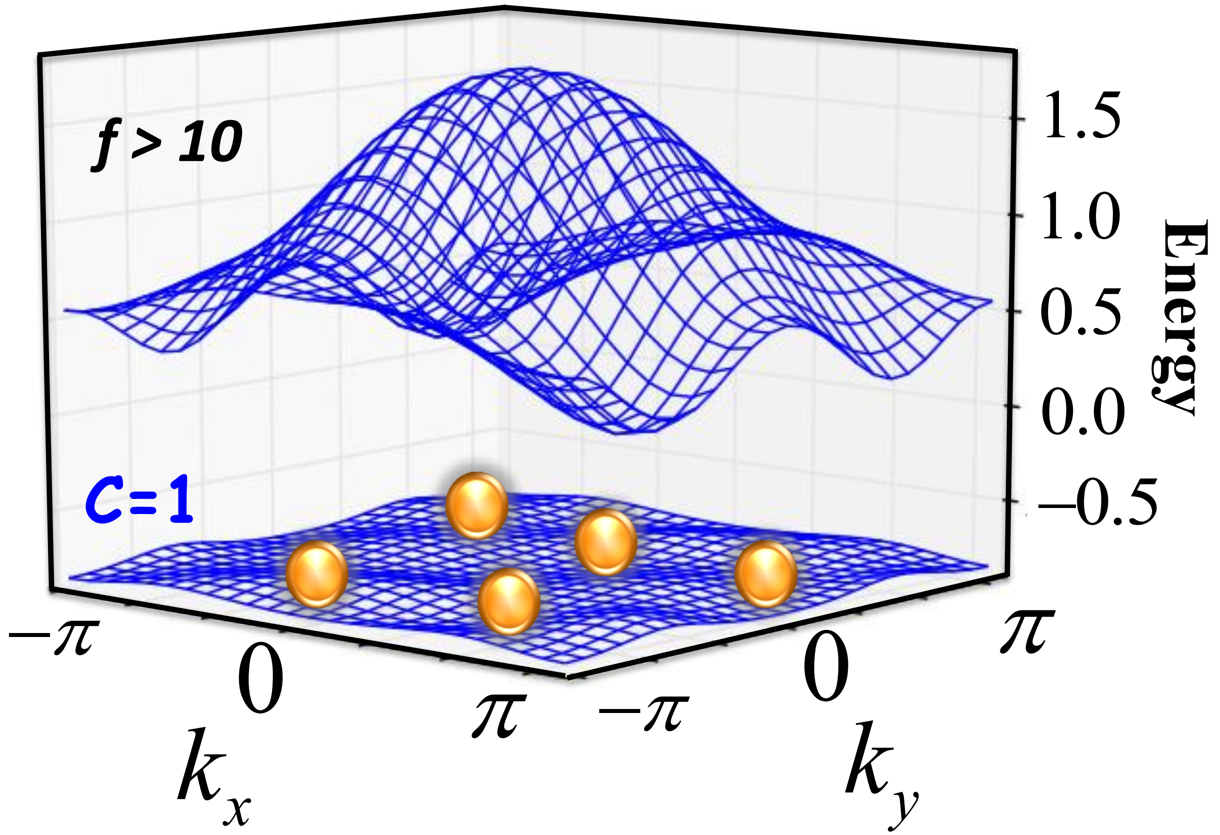


From Dipoles to Electrons

* Use optical fields to control the way molecules interaction
* Use electric fields to control strength of interaction

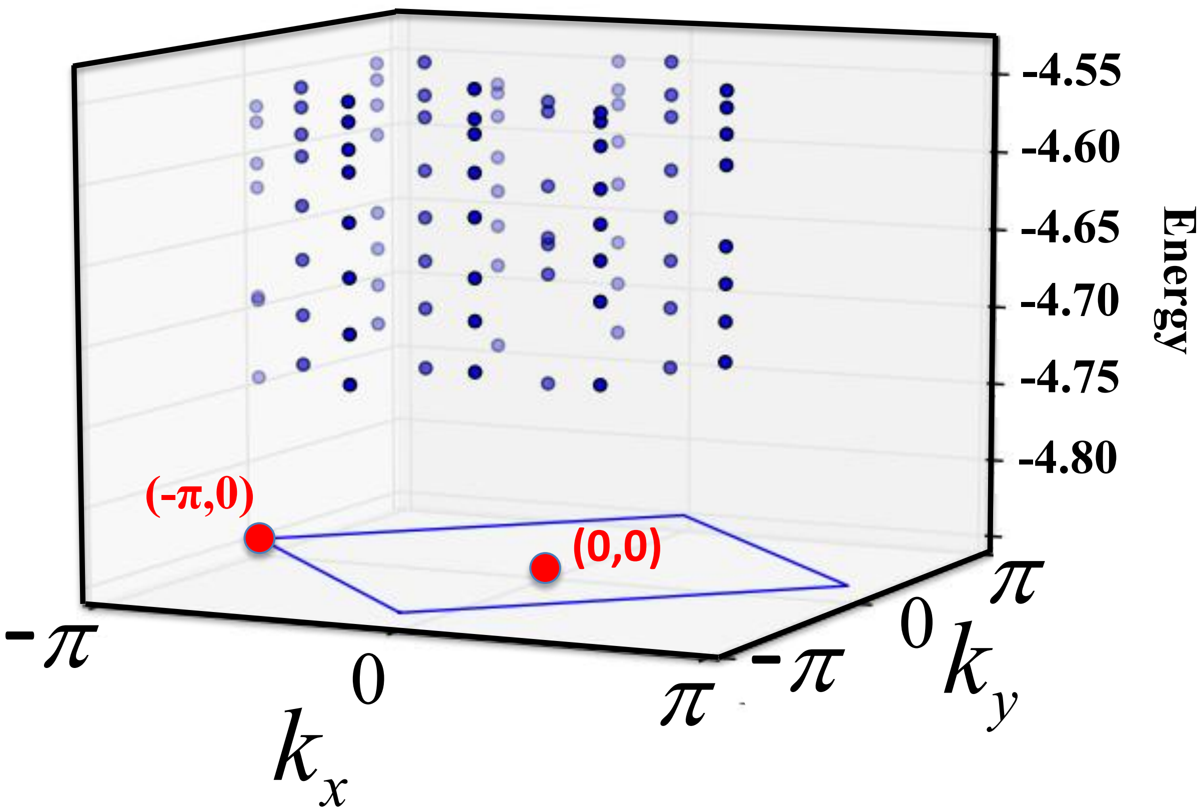


Band-structure of Dipoles

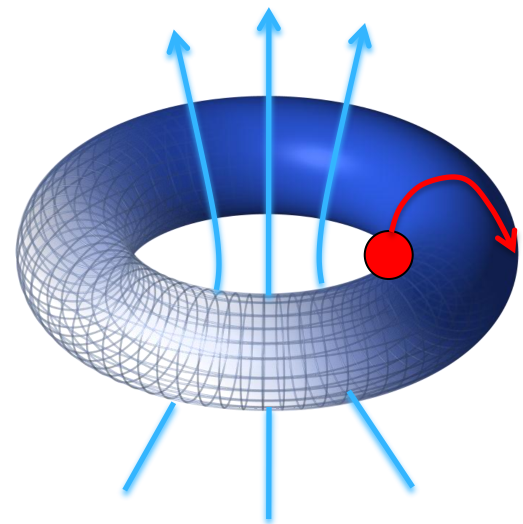


Signatures of Fractionalization

1) **Two degenerate ground states on a torus**



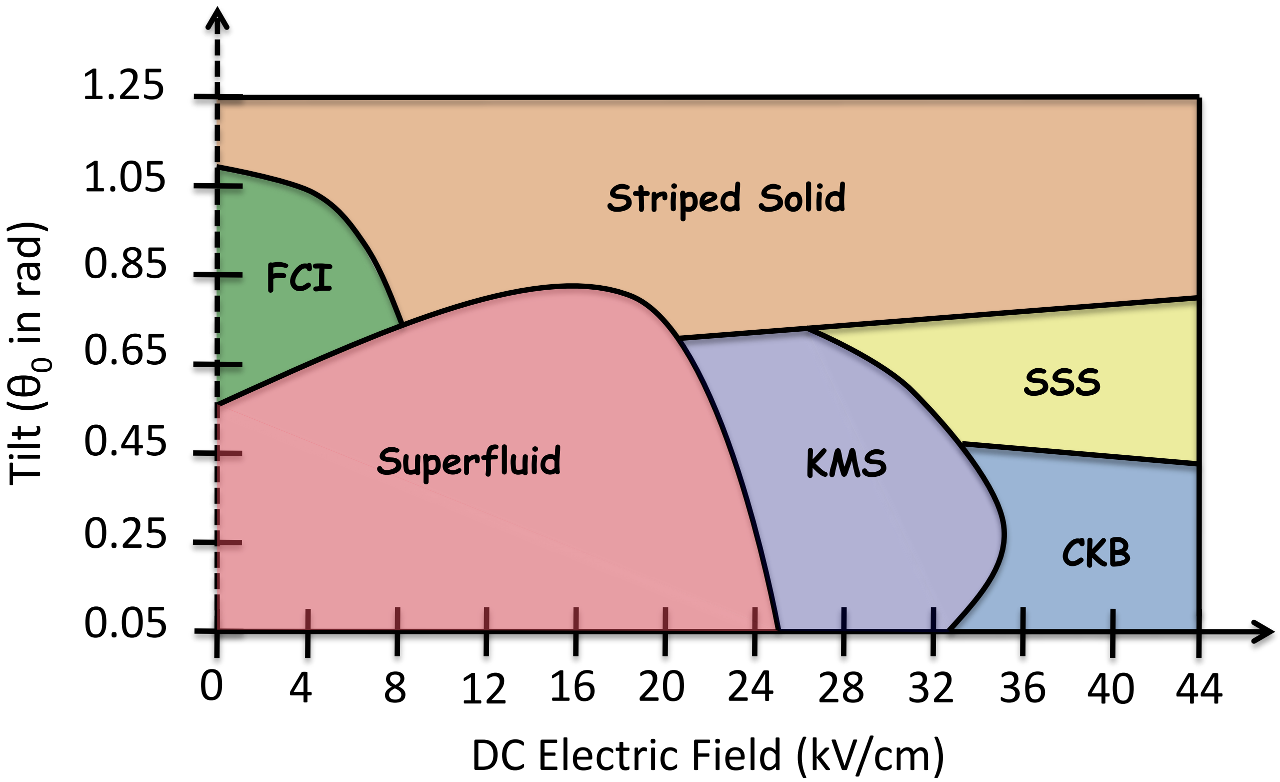
$$2\pi$$



$$\nu = \frac{1}{2} = \sigma_{XY}$$

24 Sites, 6 Particles (Finite size scaling up to 44 sites)

Competing Phases



Thanks

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Jun Ye (CU Boulder)
Mikhail Lukin (Harvard

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