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Contact us!

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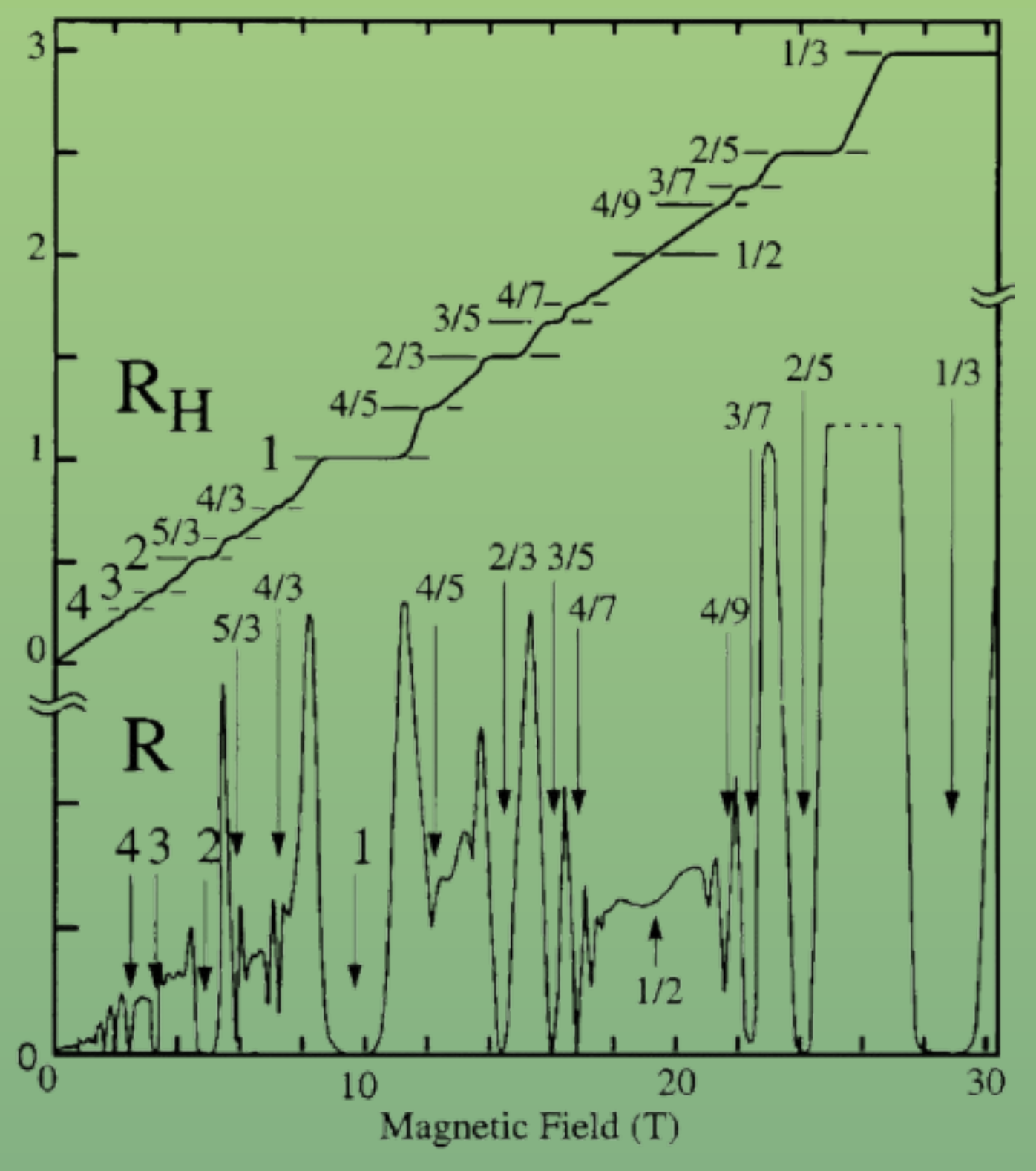
Visit our group's website!

Interactions and Topological Order

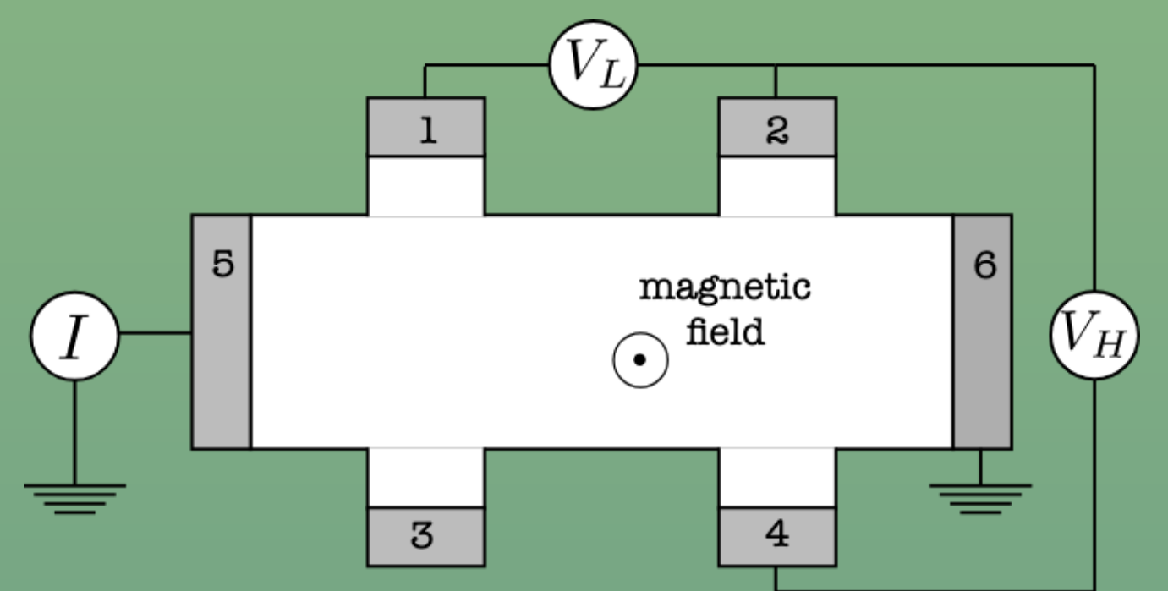
We study phases of matter where interactions between the degrees of freedom lead to novel orders, often of topological character. We tackle these complex systems using analytical methods, such as second quantisation and field theory, as well as state-of-the-art numerical techniques, such as exact diagonalisation, tensor networks, variational methods, and neural networks.

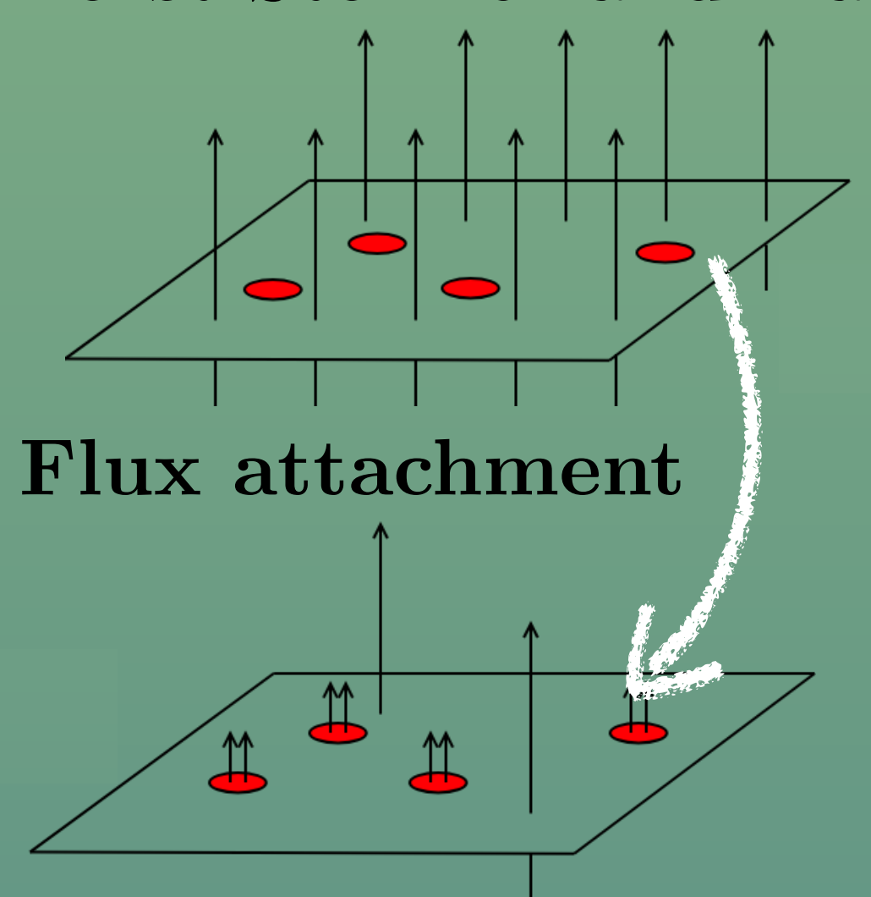
Fractional quantum Hall effect is a phenomenon in which **electrons subjected to strong magnetic fields** form novel phases of matter.

The effect is characterised by a **fractionalisation of the electron's charge, spin, exchange statistics** (and possibly other quantum numbers), leading to **anyonic** low-energy excitations.



The discovery and understanding of this effect resulted in the **1998 Nobel prize in physics** being awarded to Robert Laughlin, Horst Störmer and Daniel Tsui.



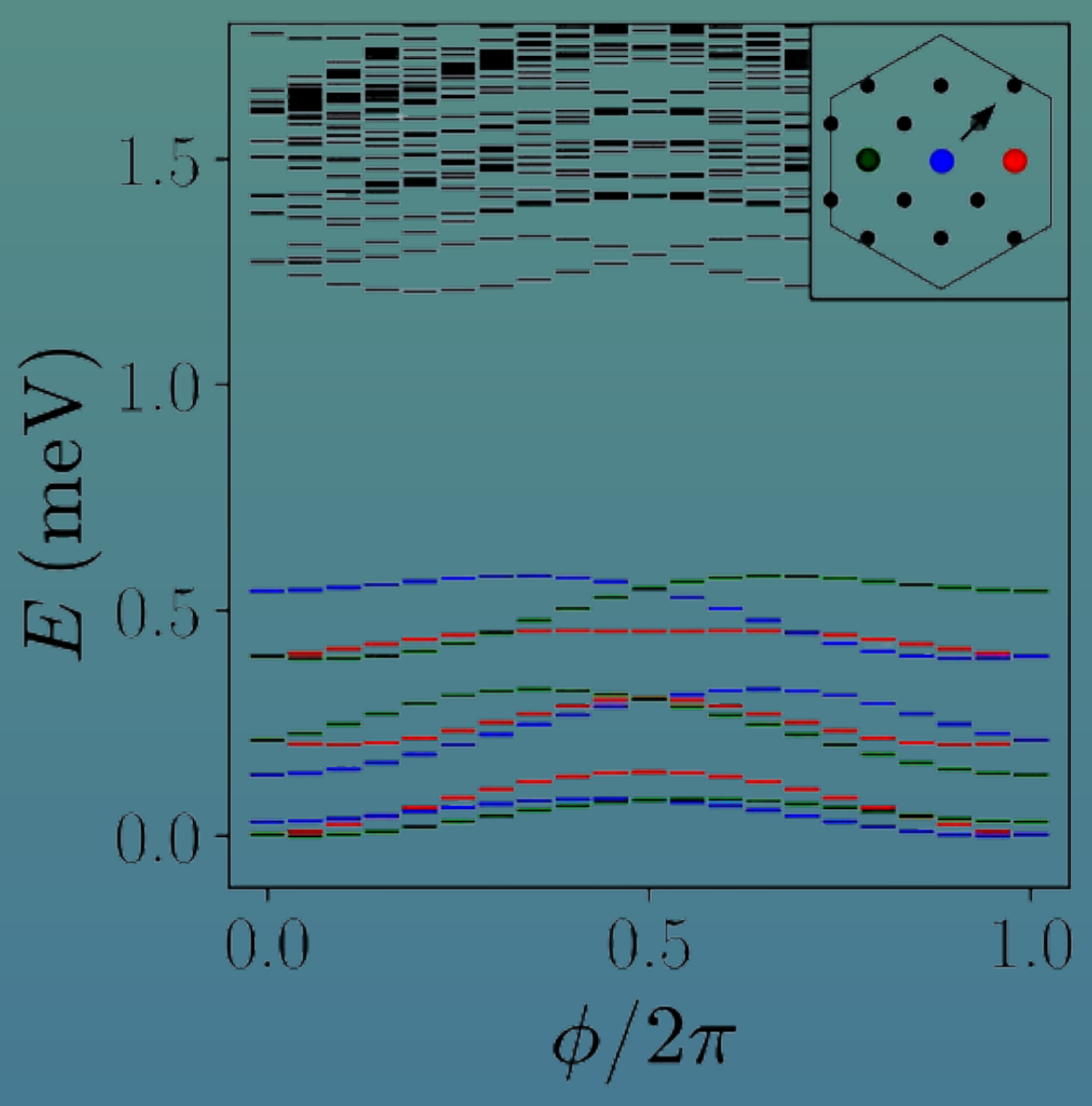


The effect was understood in part by the picture of **composite fermions**, in which electrons **bind magnetic flux quanta** to them due to repulsive interactions. The composite fermions thus experience a reduced magnetic field and can form an integer quantum Hall state.

More recently, **conformal field theory** has found applications in the study of the fractional quantum hall states. In particular, several **model states** have been proposed using conformal field theory constructions to explain FQH states observed in experiment. We thus aim to understand **how novel exotic fractional quantum hall states can be realised.**

Fractional Chern Insulators are **crystalline materials** which exhibit FQHE in the absence of an external magnetic field.

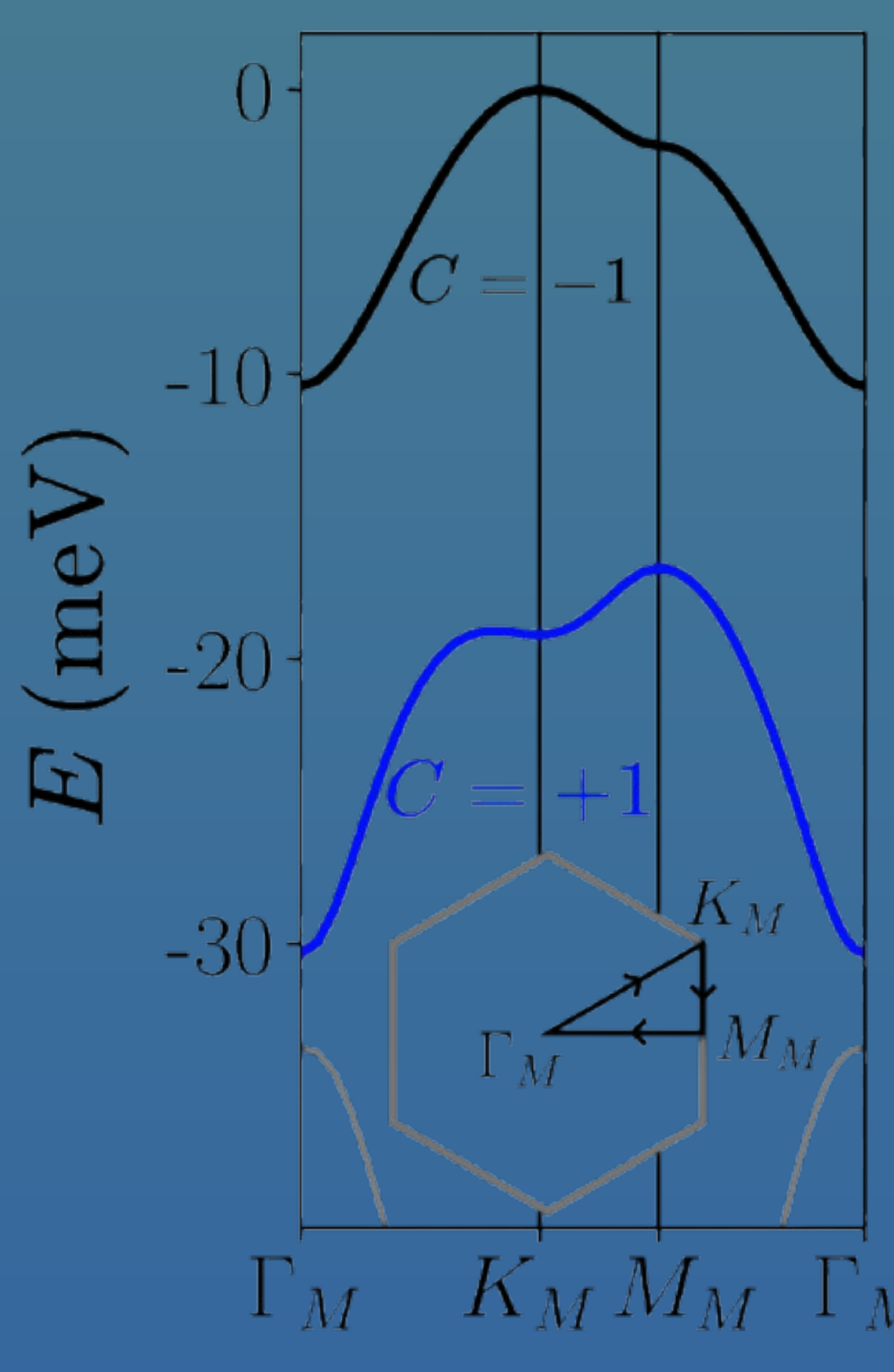
Such materials exploit their band structure's **quantum geometry** to mimic certain properties of Landau levels.



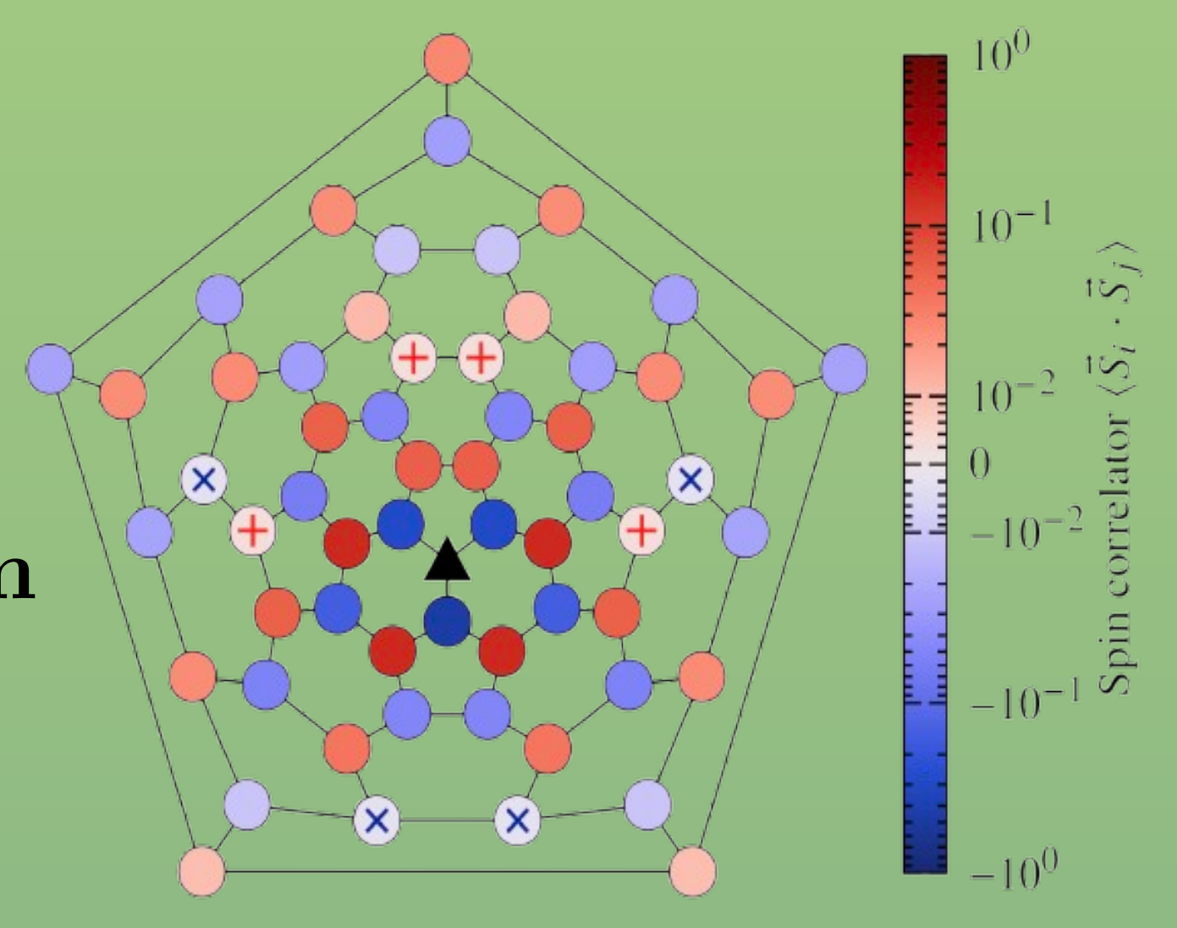
Twisted bilayer MoTe2 was recently found to be an FCI when hole-doped!

There are hopes for other **moiré materials** (2D layers with relative twist or lattice mismatch), such as twisted bilayer graphene, to also show FCI states.

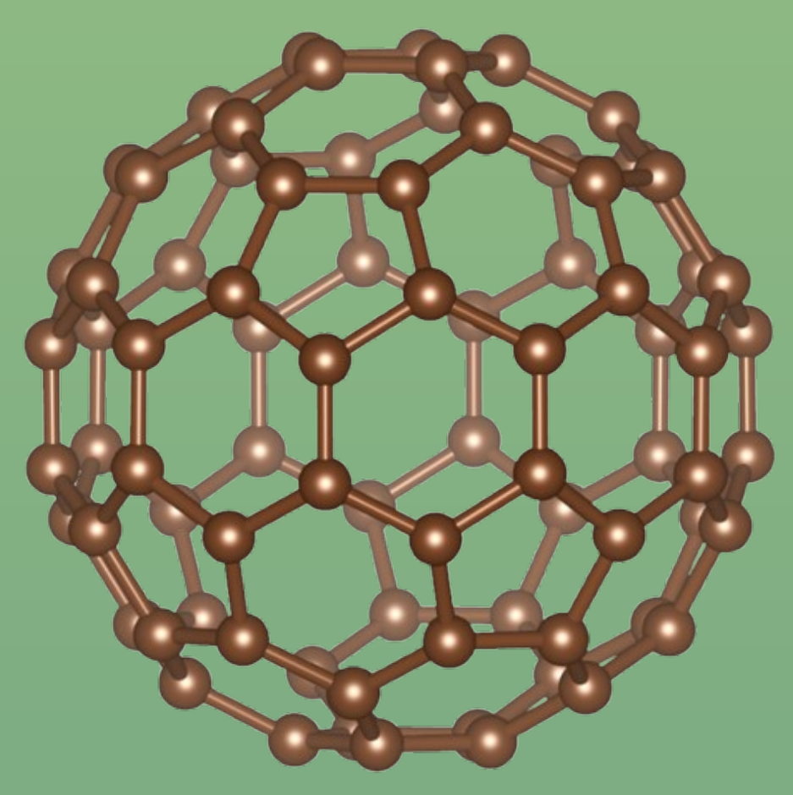
We investigate **how FCI and related phases can be realised in candidate materials**, using both microscopic **continuum models** as well as **toy model** Hamiltonians.

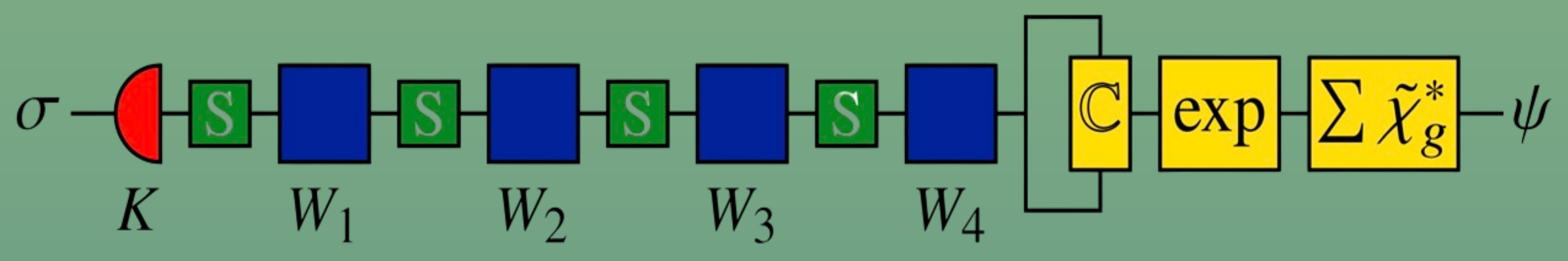


(Quantum) spin liquids are a phase of matter of interacting spins where interactions prevent the formation of conventional magnetic order. They are characterised by **excitations** carrying **fragmented quantum numbers** (e.g. spinous with no charge but spin-1/2), **long-range entanglement**, and and **highly degenerate ground states.**



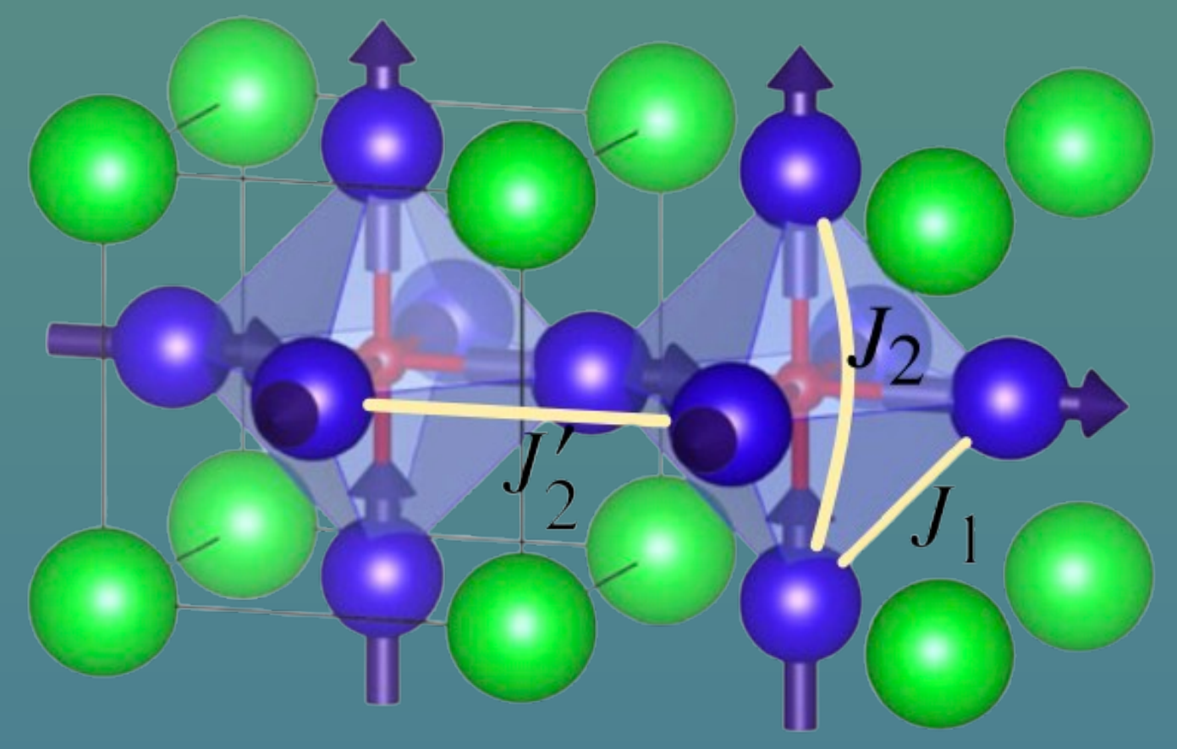
Frustrated magnets arise when **competing magnetic interactions** in a material impose constraints on the spin arrangement of the electrons which **cannot be satisfied simultaneously**. This prevents long-range magnetic order from forming, with the spins preferring to form a spin liquid instead.





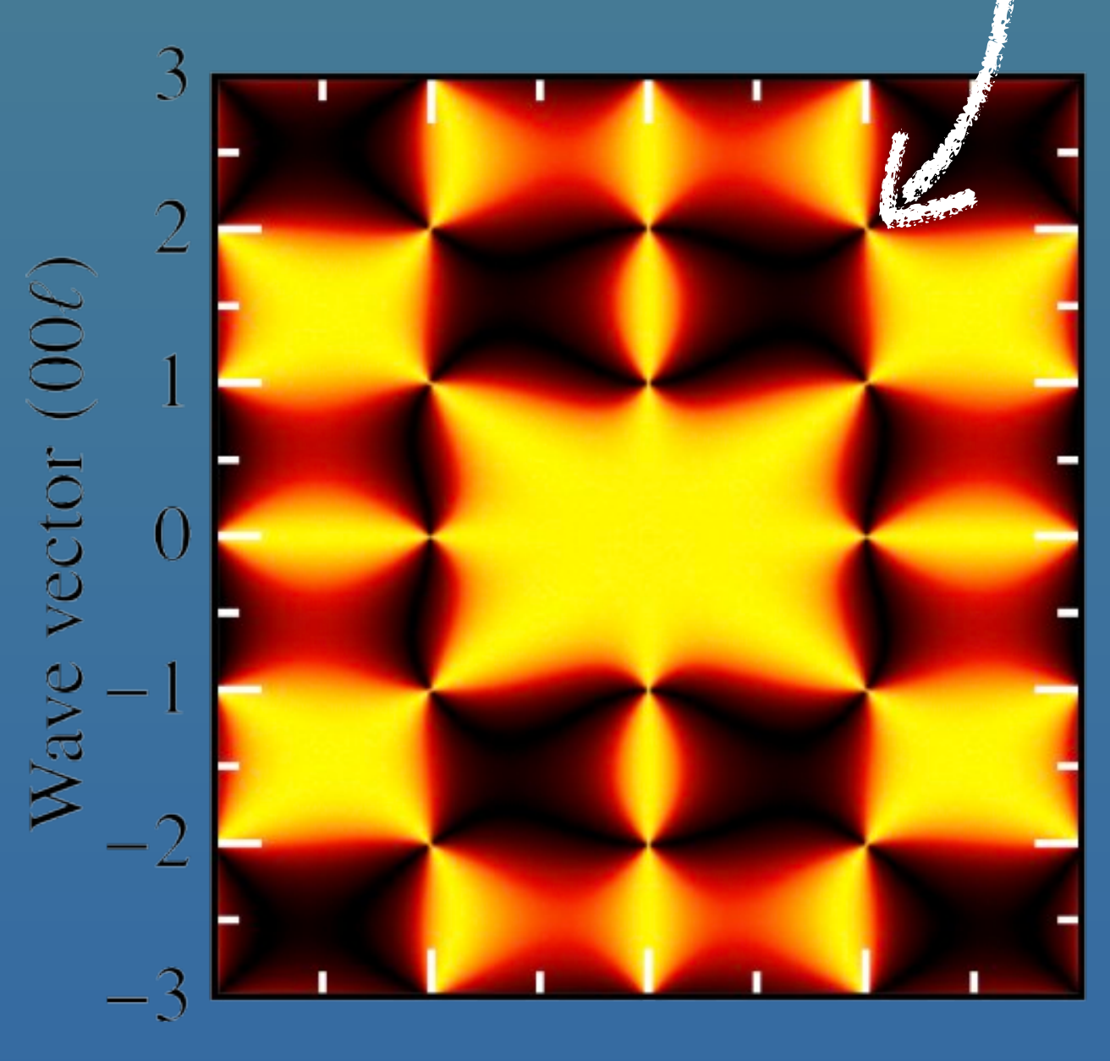
Convolutional neural networks combined with **variational Monte-Carlo methods** provide a powerful approach to tackle the quantum many-body problem. Instead of manually enforcing symmetry constraints on wave function ansätzes, one can instead use CNNs to approximate quantum states, forming **neural quantum states**, and then perform the symmetrisation more efficiently using a plethora of machine-learning based protocols.

This strategy has recently been employed by our group to study **Heisenberg models on fullerenes**, and **J1-J2 models on geometrically frustrated lattices**.



(Quantum) spin ice is yet another form of frustrated magnetism which fails to order even at low temperatures. As such, it can be viewed as a spin liquid. Notably however, the spin arrangements of the ground states obey some rules, known as **ice rules**, and are thus not completely "disordered".

Pinch point!



Spin ice typically arises in spin models on lattices with **corner-sharing tetrahedra** (or more complicated polytopes). Here the ice rules take the form of **2 spins pointing in** and **2 spins pointing out** in each tetrahedron.

Low energy excitation in the form of local violations of ice rules behave like (possibly **deconfined) magnetic monopoles.**

Dynamics of spin ice is thus described by **emergent QED theory.**