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Interacting (topological) quantum matter

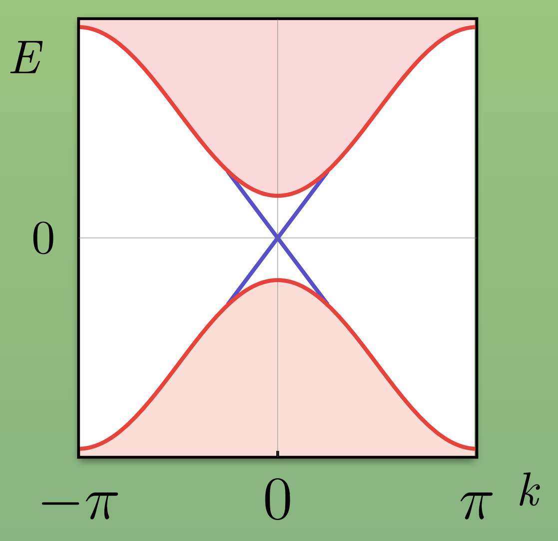
We study crystalline materials, where interactions between the degrees of freedom cannot be treated perturbatively. We tackle these complex systems using analytical methods, such as topology and group theory, and numerical techniques.

Landscape of topological phases: a key feature of topological states is the existence of protected boundary modes, which can emerge from different types of topology. What kind of phases can appear when we add correlations in electronic crystalline systems?

Entanglement range

0

Topological insulators (non-interacting)



10-fold way, Topological quantum chemistry, Symmetry indicators ...

The topology of non-interacting electronic crystals has been studied extensively, and has lead to the prediction and discovery of many intriguing phases of matter.
One of the theories used to analyse crystals is the one of "topological quantum chemistry", which relies on the existence of a band structure, and non-interacting reference states.
How can these theory be adapted once we include interactions?

short

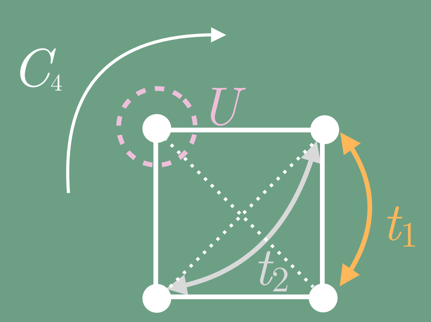
Symmetry protected topological states (SPT)

Gapped (Single GS)
No exotic excitations

String order parameters, Partial symmetry operation...

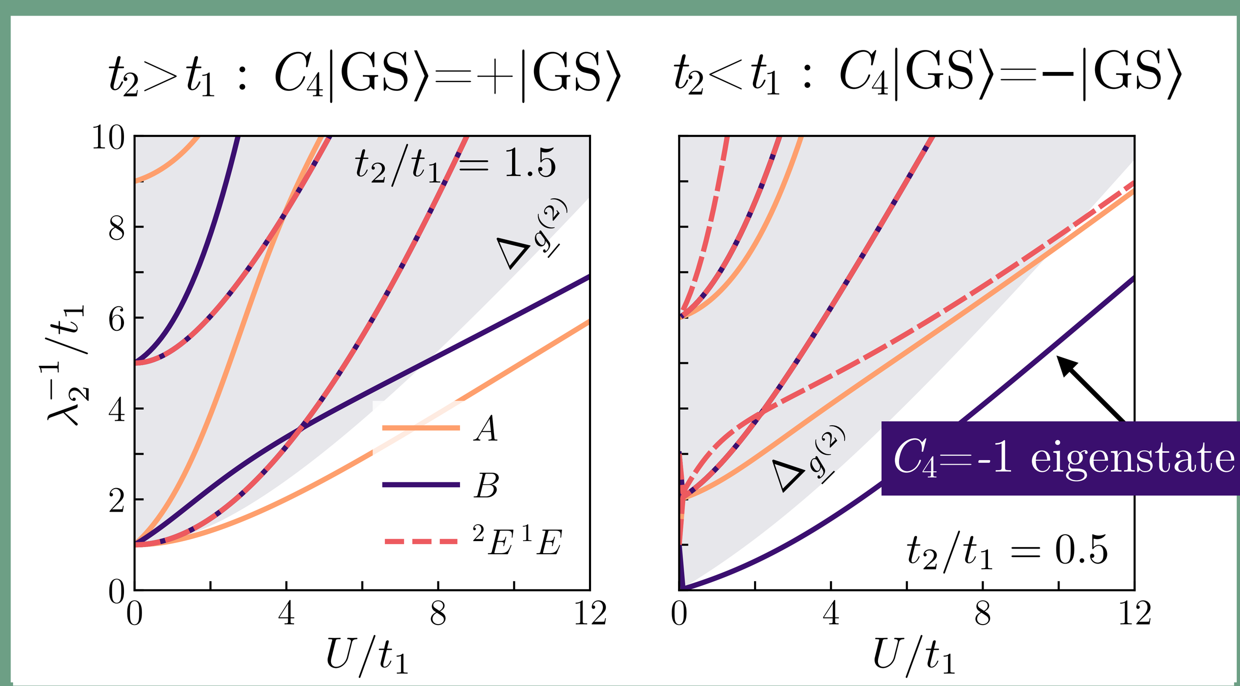
Interacting topological quantum chemistry is a theoretical framework to identify interacting short-ranged states. We define a class of trial wavefunctions, the n-Mott atomic limits (n-MALs), and we classify them with the n-particle Green's function

The Hubbard square is our example of building block for 2-MALs. The ground state at $t_2 < t_1$ is disconnected from any non-interacting ground state with time reversal symmetry.



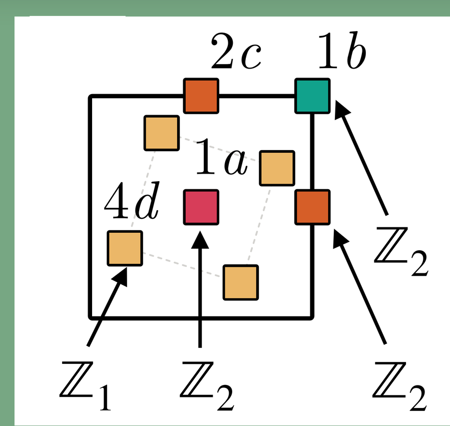
Electrons hop with amplitude t_2,t_1, and interact through the Hubbard interaction.

The two-particle Green's function distinguishes the two cases!



The n-MAL states belong to the symmetry-protected crystalline phases

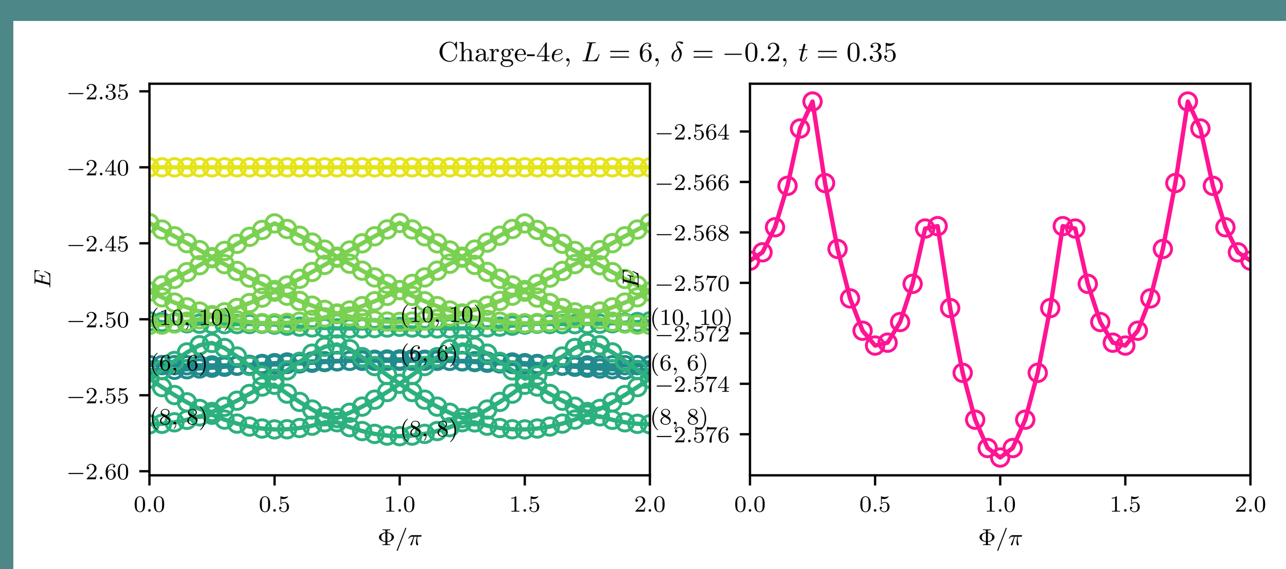
$$|n\text{-MAL}\rangle = \prod_{\boldsymbol{r}} \prod_{\xi \in \text{occ.}} \hat{O}^\dagger_{\boldsymbol{r},\xi} |0\rangle \qquad \hat{O}^\dagger_{\boldsymbol{r},\xi}\text{: } n\text{-particle operators}$$



Our article:

Which other states can be realised with crystalline symmetries?

Charge-4e superconductivity is a phase where electron 'quartets' condense into a superfluid, instead of Cooper pairs. We propose an attractive Hubbard model where this phase appears as a ground state

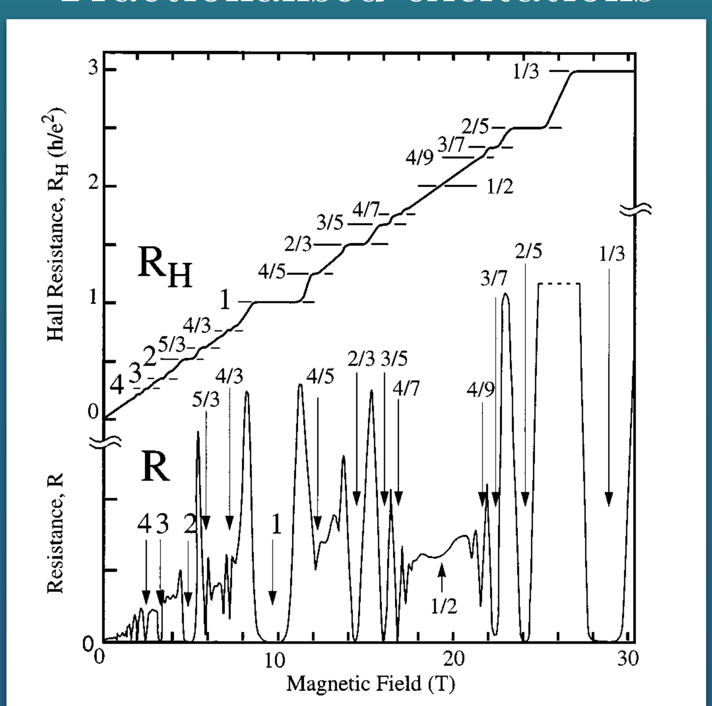


If topological, this phase may lead to novel superconducting SPT phases!

long

Topological order

Fractionalised excitations



Example: Fractional quantum Hall effect

Fractional Chern insulators realise the physics of the fractional quantum Hall effect in lattice systems, and they are an example of topological order in crystalline systems. Recently, this has been experimentally observed in 'twisted bilayer' materials.

Experiment measures a fractionally quantised resistance. [Park et al., *Nature*, 2023]