Phase Transitions in Quasiperiodic Systems

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‘IST Physics Frontier Symposium’ - Instituto Superior Técnico

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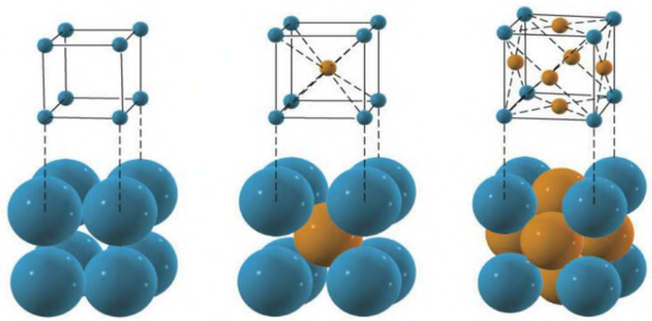
Introduction

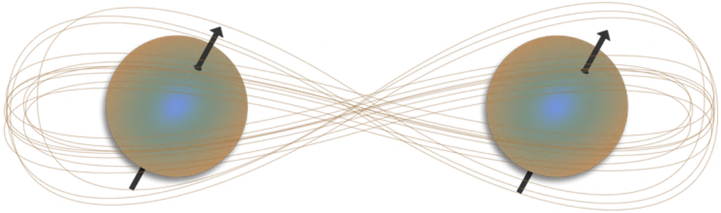
Condensed Matter Physics

- Branch of physics that studies the **physical properties** of **systems with many particles**, such as solids and liquids;
- Seeks to understand how **interactions between particles** give rise to these properties.



Quantum Matter Physics

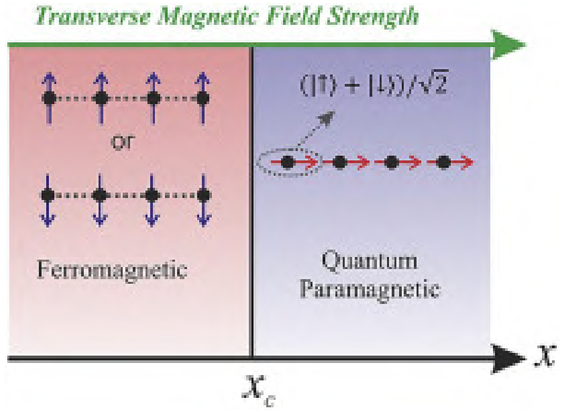
- Subfield of Condensed Matter Physics that studies systems where **quantum effects dominate** the behavior;
- Describes phases of matter and properties that have no classical equivalent and **can only be explained by quantum mechanics.**

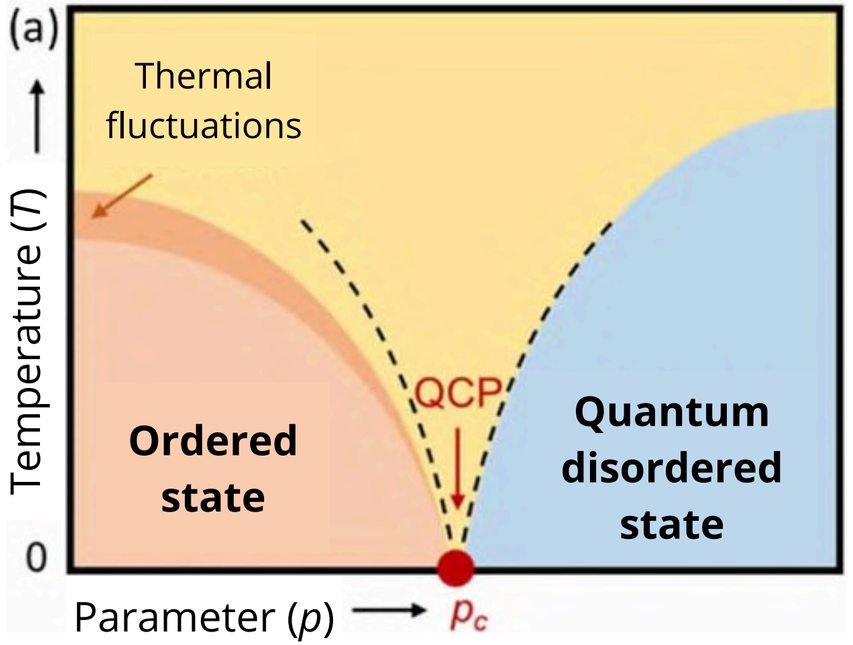


What is a Phase Transition?

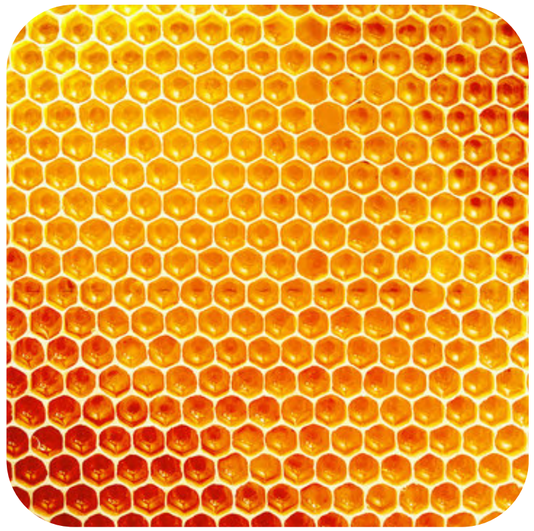
Phase Transition: Abrupt changes in the properties of a system when a control parameter is varied.

- **Classical:** Occur due to thermal fluctuations.
- **Quantum:** Occur at zero temperature ($T = 0$). They are caused by quantum fluctuations.



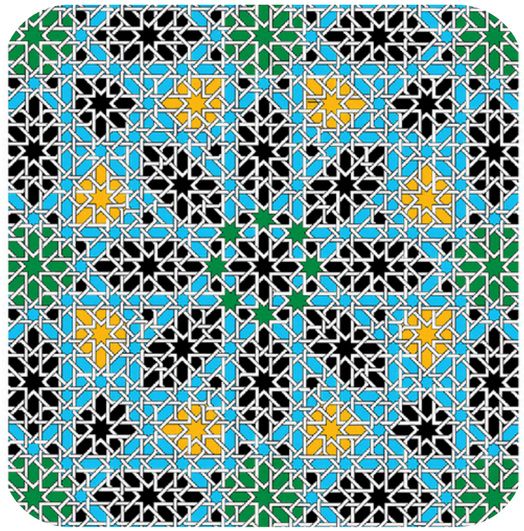


Types of systems



Periodic

Disordered

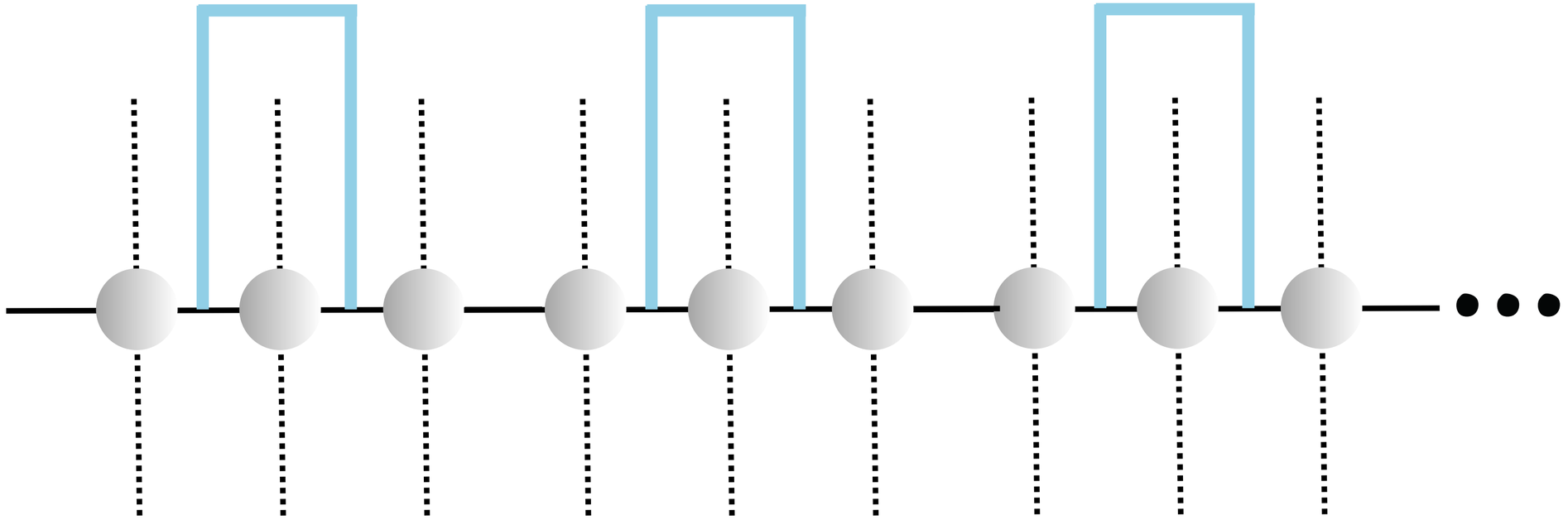


Quasiperiodic

How to create these systems to study them? → Apply **an external potential** with the **desired structure**!

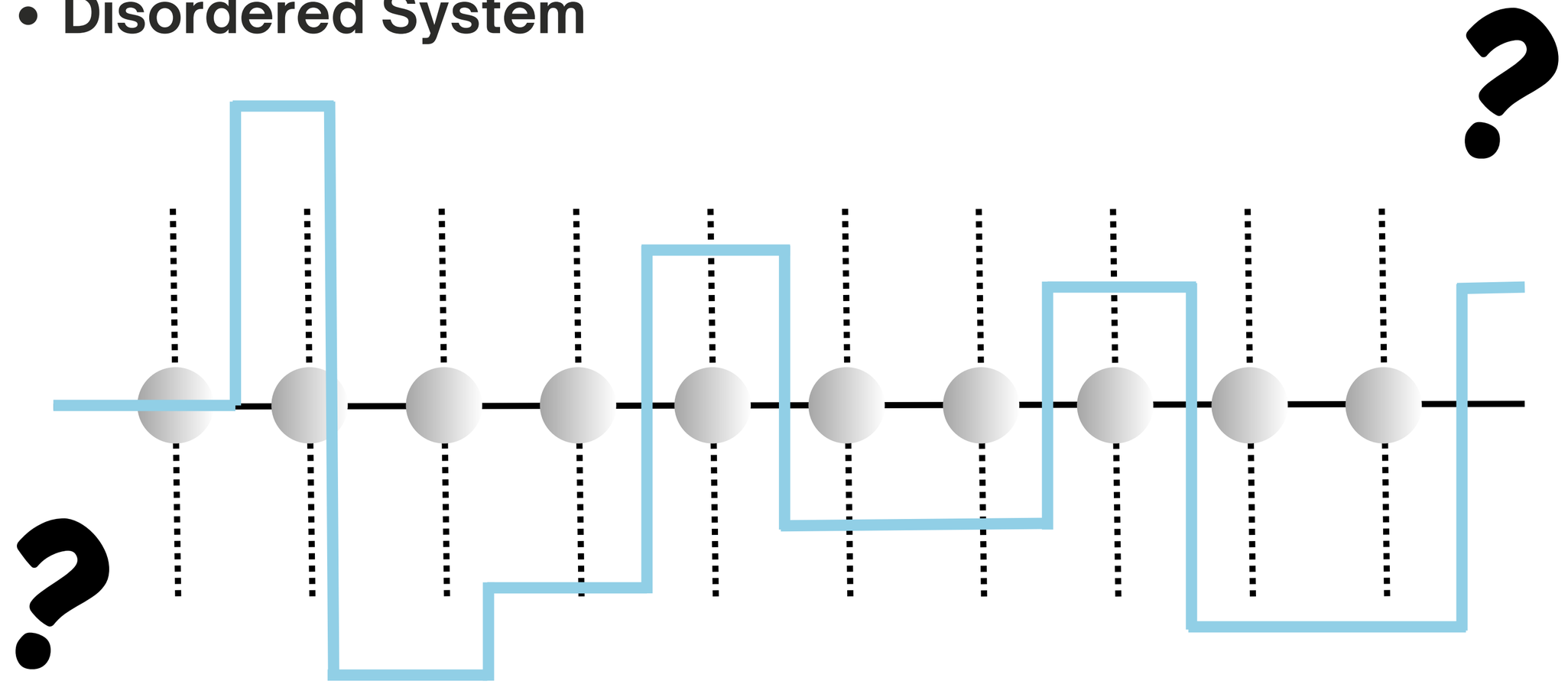
Types of systems

- **Periodic System**



Types of systems

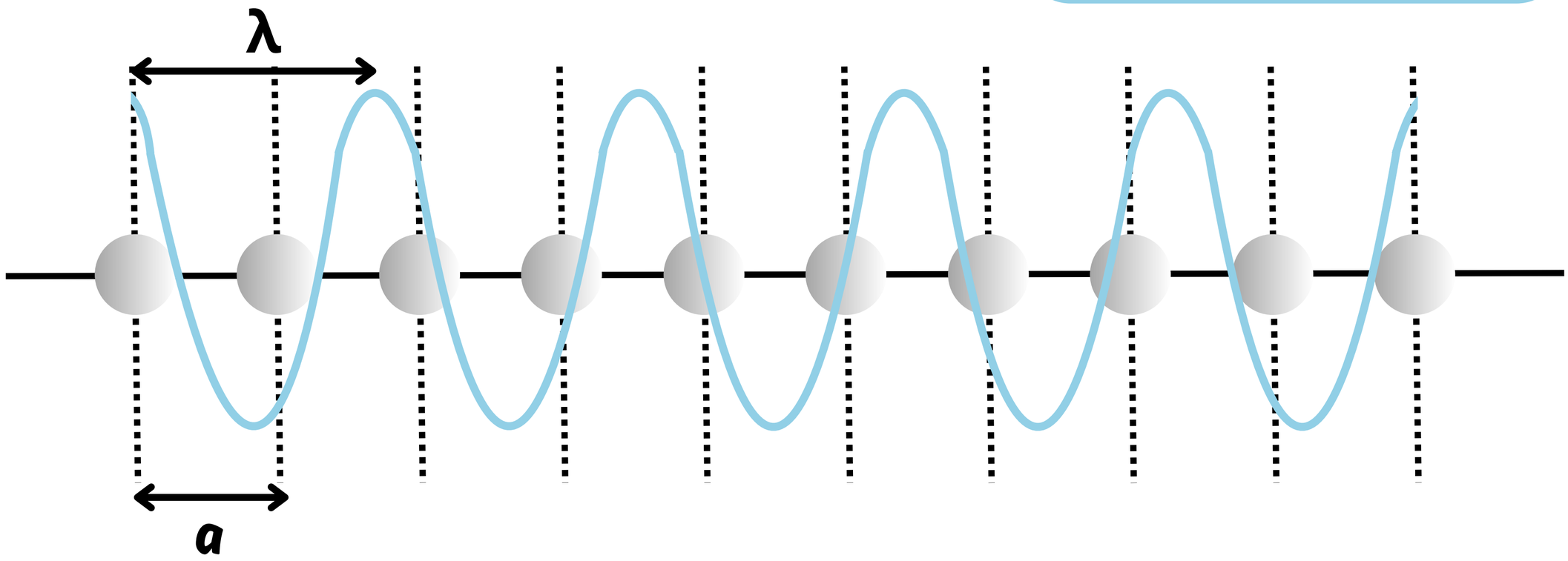
- Disordered System



Types of systems

- Quasiperiodic System

λ/a has to be an irrational number!

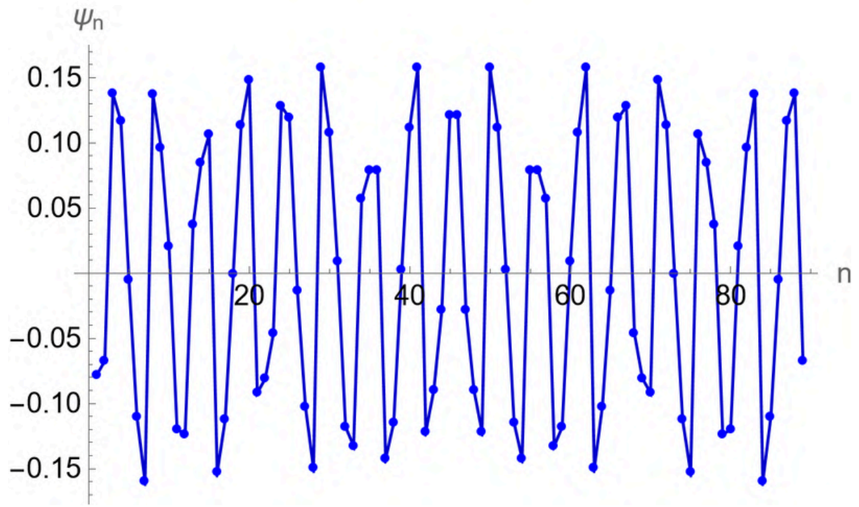


Localization Transitions

- Quasiperiodicity introduced by a potential term of the form $V \sum_n \cos(2\pi\tau n + \phi) c_n^\dagger c_n$

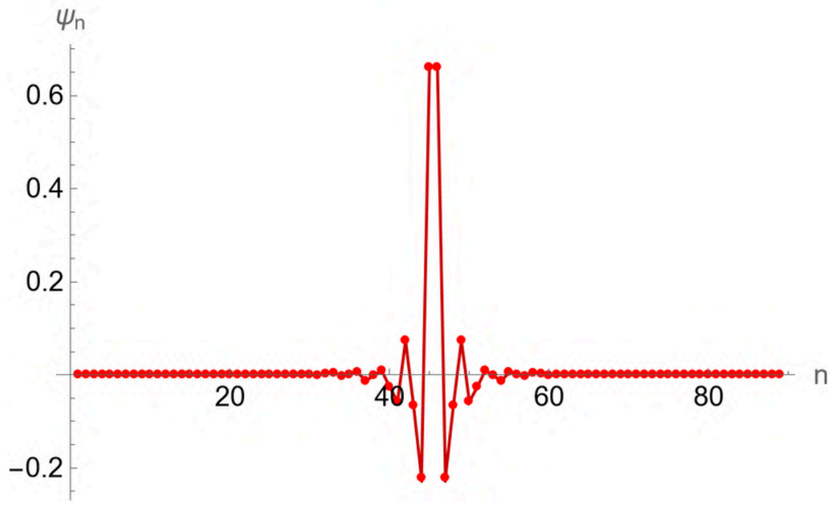
$\tau = a/\lambda \notin \mathbb{Q}$

Increasing the intensity of the quasiperiodic potential V, a <u>localization phase transition</u> is observed!



Delocalized phase (V < 2)

Increase in V



Localized phase (V < 2)

Interactions - previous studies

- Study **interactive** systems of **particles without spin** → to see how those interactions affect the nature of transition

Metrics approach **unity** (non-interacting value) around the **critical point**

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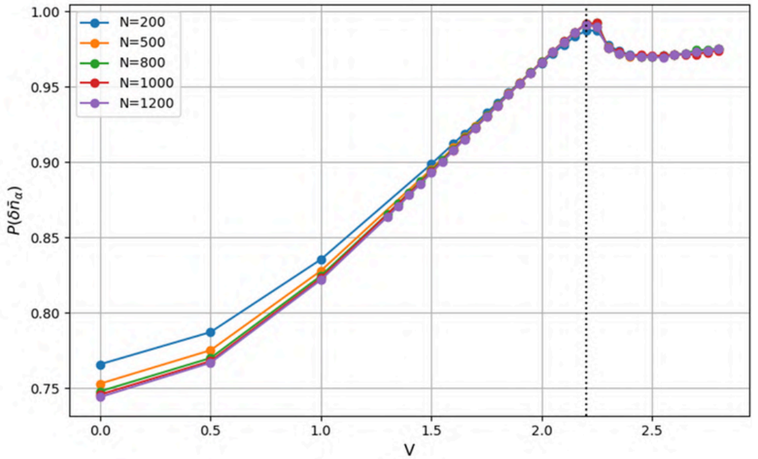
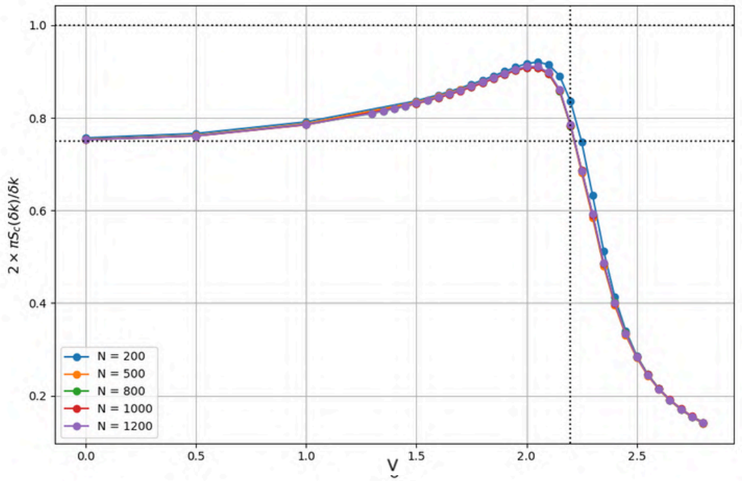
Under the influence of these interactions, **excitations** near the transition behave as **non-interacting!**





Occupation Inverse Participation Ratio	Luttinger Parameter
$P(\{\delta\bar{n}_\alpha\}) = \frac{\sum_\alpha \lvert\delta\bar{n}_\alpha\rvert^4}{(\sum_\alpha \lvert\delta\bar{n}_\alpha\rvert^2)^2}$	$S_c(k) = \frac{1}{N}\sum_{jl} e^{ik(x_j - x_l)}[\langle n_j n_l\rangle - \langle n_j\rangle\langle n_l\rangle]$ $K_c = 2\pi \lim_{k\to 0} S_c(k)/k$

Interactions - previous studies

- Study i**nteractive** systems of **particles without spin** → to see how those interactions affect the nature of transition

- Conclusion:

- **Transition persists** even in the presence of this type of interactions;
- **Properties of the transition are preserved, i.e. unchanged by the interactions.**

↓

<u>Spinless interactions are irrelevant to the transition!</u>

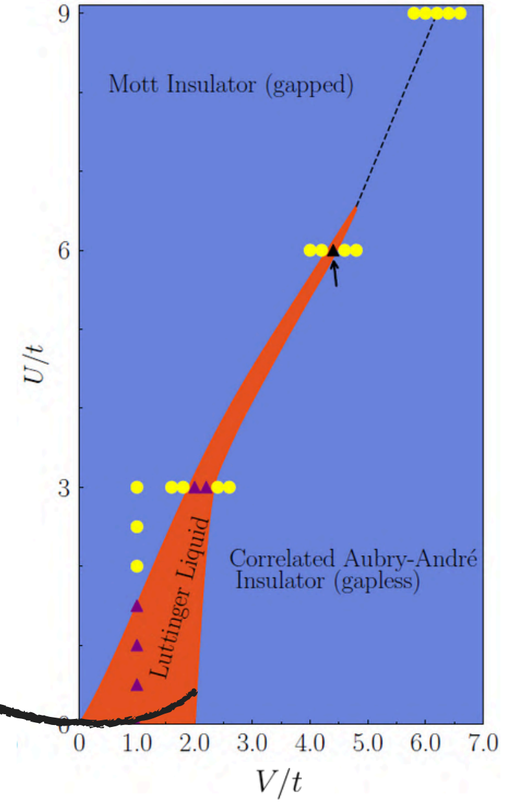
My project: Motivation

Objective: Investigate interactive quasiperiodic systems of particles <u>with spin</u>

- **Conclusion from previous studies:**

Model with spinful interactions exhibits a **localization transition driven by V**, but its **properties** remain unexplored!

- **Main focus of the thesis**:
  - Establish the properties of this transition;
  - Investigate the effects of electronic interactions on the transition.



[Chi et al., arXiv:2401.08980 (2024)]

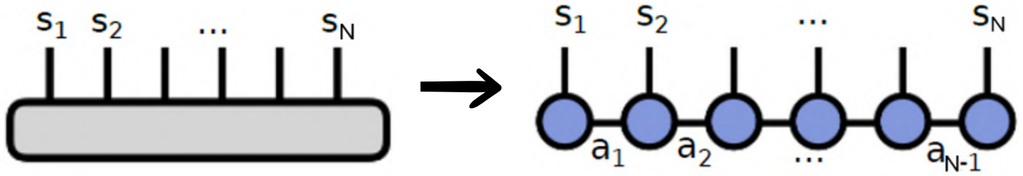
My project: Numerical Method

Density Matrix Renormalization Group (DMRG)

- **Limitation:** Total Hilbert space size scales exponentially with system size;
- **Solution**: This method overcomes exponential growth of total Hilbert space.

Variational method that determines the **ground state** of **many-body Hamiltonians** with **polynomial complexity**

Using a **Matrix Product State** (MPS) representation



My project: Results

Objective: Investigate interactive quasiperiodic systems of particles <u>with spin</u>

- **Results**:

- **Excitations near the transition** seem to be **interacting**;
- **Properties** and **nature** of the transition seem to change, i.e be **modified by spinful interactions**.

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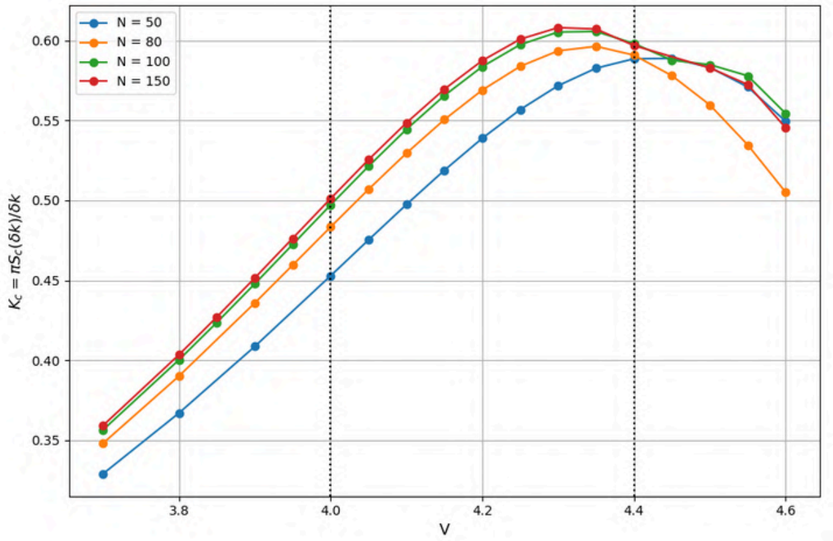
<u>Spinful interactions appear to be relevant to the transition!</u>



Luttinger Parameter $K_c \neq 1$
(its non-interacting value)
near the transition

Thank you for the attention!
Any questions?

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