# New Quantum States for Qubits

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## Introduction

- Generally the nonequilibrium dynamics of isolated, strongly interacting quantum systems eventually go to thermal equilibrium (thermalize).
- This is a problem for quantum computing, as information is lost when entropy is maximised in this way
- New research shows a new type of system which resists thermalisation, leading to longer lasting qubits, and paving a way forward for quantum computing

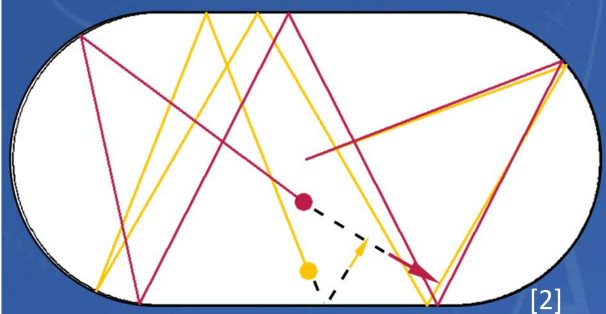
## Background

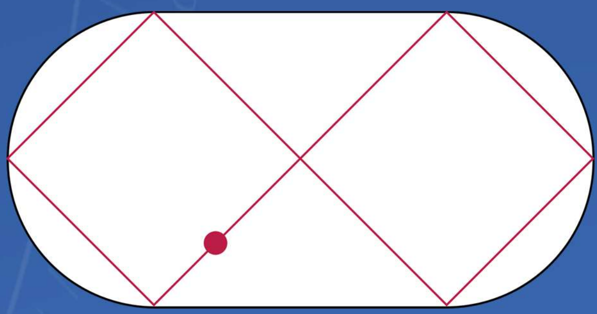
### Ergodicity & Chaotic systems

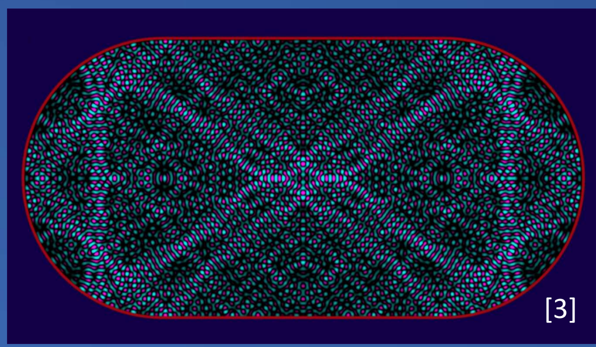
- Ergodicity is the ability of a system to explore all available states over time
- This is used as a fundamental principle of statistical mechanics (e.g. Ideal Gas Law)
- Chaotic systems exist when a tiny nudge in input results in a drastically different output (bottom left), these often exist with many interacting particles
- However we can get unstable periodic orbits in chaotic systems which make them non-ergodic (bottom right)

### Quantum Scars

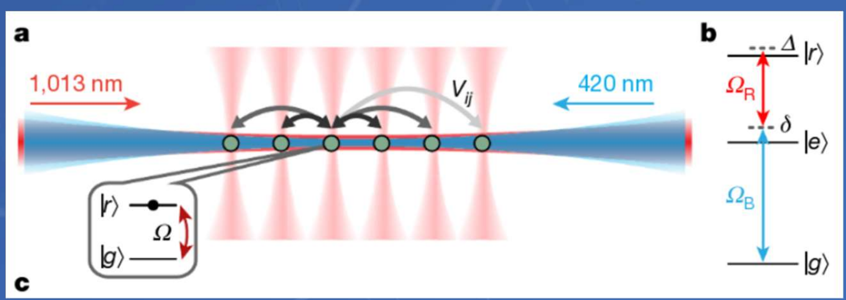
- The classical unstable periodic orbits carry over to quantum systems [1]
- This is surprising as we might expect the classical effects to not carry over to the quantum mechanical realm
- A special configuration leaves an imprint or a scar on a particle's state, keeping it from filling the entire space
- These ideas can be extended to multiple particles which are all interact with each other in complicated ways, in quantum many body scarring



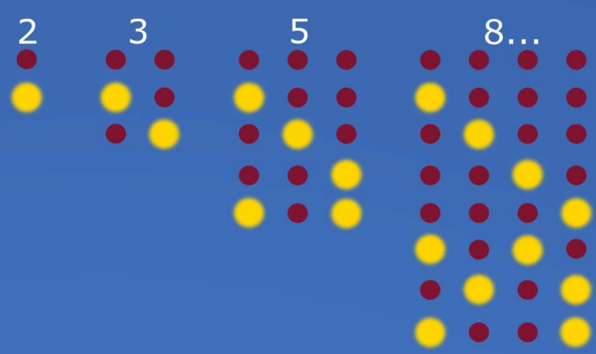



## Experiment




- Work by Bernian *et al* [4] experimentally created a quantum simulator containing 51 qubits of equally spaced cold atoms in a row, which could be placed in a highly excited Rydberg state or a ground state
- It can be shown this system thermalizes for general initial states, but when every other atom was excited (see below) oscillations persisted for at least 10 times longer. This is not expected!

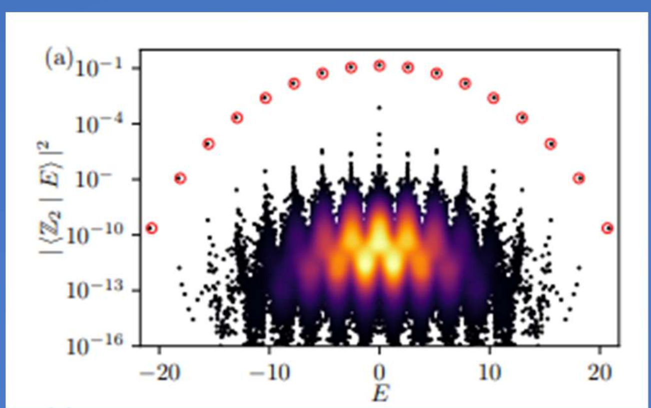
## Working model




- In the model of the experimental system, two excited Rydberg atoms cannot be next to each other
- This means the number of possible states expands with the Fibonacci sequence
- To model this a Hilbert space of an effective model of Fibonacci anyons was used[5]
- A "PXP Hamiltonian" is used to model the change of states of this system [5]

## Scarred States

- Decomposing the model of the experimental system, a band of special states was found, which were said to be strongly scarred [5]
- The periodic experimental configuration projects strongly onto these scarred states
- These non-thermal scarred states undergo periodic revivals
- A method called "Forward Scattering Approximation" (FSA) was created which can find these accurately [5]
- FSA has a 1% error looking at 32 qubits and efficient computation time (polynomial time)




## Weak Ergodicity Breaking

- To avoid thermalisation "Two well-studied possibilities include many-body localization in strongly disordered systems, and fine-tuned integrable systems" [6]
- Neither of these are able to explain the Rydberg atom experiment [5]
- To explain this, the states of quantum many-body scars was developed that weakly broke ergodicity in this system [5]
- Here ergodicity is weakly broken because only specific initial states are non-ergodic

## Conclusions

- Quantum many-body scarring is used to explain the periodic revivals in the Rydberg atom experiment by Bernian *et al*, and could be a new way of resisting thermalisation in quantum computers
- Quantum many-body scarring could potentially be a new universality class as it has been found to exist in other systems [7]
- A new area of "partially non-ergodic" systems has been opened up, which is not yet fully understood,
- It is also not understood how or when these quantum many-body scars appear, this theory must be generalized and made more rigorous

## References

[1] E. J. Heller. Physical Review Letters 53 16, 1515–1518 (1984)
[2] M. Woo, Quanta Magazine (2020).
[3] J. Scholbach, Visual Insight (2020).
[4] H. Bernien, et al. Nature 551 7682, 579–584 (2017)
[5] C. Turner, A. Michailidis, D. Abanin, M. Serbyn and Z. Papić, Nature Physics 14, (2018).
[6] C. Lin and O. Motrunich, Physical Review Letters 122, (2019).
[7] M. Schecter and T. Iadecola, Physical Review Letters 123, (2019).

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