TÉCNICO LISBOA

Spectral signatures of decoherence

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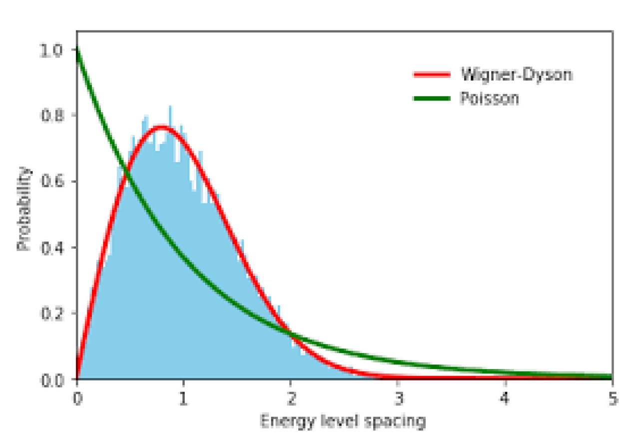
Abstract

Chaos in closed quantum systems has provided valuable insights into the universal properties of generic quantum dynamics. These principles have recently been extended to dissipative systems governed by Lindblad dynamics. However, applying these signatures of dissipative chaos to maps can be challenging near unitarity, due to their extreme spectral anisotropy. In this regime, the influence of dissipation on promoting or inhibiting chaotic behavior remains largely unexplored. In this work, we examine how the spectral features of quantum integrability or chaotic unitary dynamics change once dissipation is introduced.

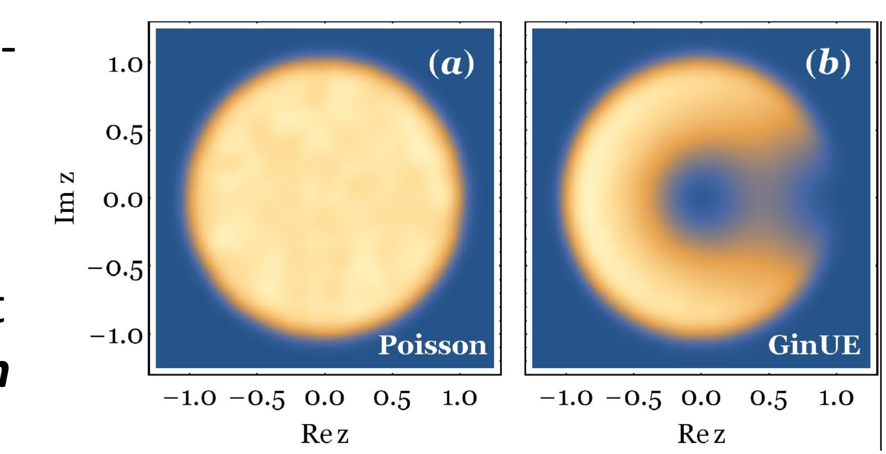
Introduction and Motivation

Closed systems



- Quantum chaos conjectures in closed systems: level spacing follows Poisson (Wigner-Dyson) distribution if the system is integrable (chaotic).
- In open systems measures such as complex spacing ratios have been explored: distributes uniformly (as a 'bitten doughnut') in the unit circle for integrable (chaotic) systems.
- Systems with an intermediate degree of dissipation are important since this is where most real devices stand. We want to answer the question ***what is the influence of dissipation in this regime on chaotic systems?***

Open systems



Quantum Map

Diluted Unitary: Quantum map that allows to **control** between unitary and completely chaotic evolution.

$$\Phi = (1-\kappa) U \otimes U^* + \kappa \sum_{j=1}^{r} M_j \otimes M_j^*$$

- $\kappa = 1$ → Structureless
- $\kappa = 0$ → Unitary

U: Randomly sampled **integrable** and **chaotic**

M_j: Randomly Sampled always the **same** way

What happens when we increase κ?

Sampling

Kraus operators: r matrices with $d \times d$ dimensions

Sample rectangular matrix from GinUE

↓

Perform QR decomposition

↓

$$Q = \begin{pmatrix} Q_{1,1} & \cdots & Q_{1,d} \\ \vdots & \ddots & \vdots \\ Q_{d,1} & \cdots & Q_{d,d} \\ Q_{d+1,1} & \cdots & Q_{d+1,d} \\ \vdots & \ddots & \vdots \\ Q_{2d,1} & \cdots & Q_{2d,d} \\ \vdots & & \vdots \\ Q_{rd,1} & \cdots & Q_{rd,d} \end{pmatrix} \begin{matrix} M_1 \\ M_2 \\ \vdots \end{matrix}$$

Unitary Operators

Chaotic
Random matrix sampled according to the **Haar measure** of the unitary group (CUE)

Integrable Spin-1/2 chain
Square **Brick-wall**, with $\check{R}$ matrix from **XXX-model**, with random parameter δ

$$\check{R}(\delta) = \frac{\mathbb{I} + i\delta P}{\mathbb{I} + i\delta} \quad P_{j,j+1} = 1/2(\mathbb{I} + \boldsymbol{\sigma}_j . \boldsymbol{\sigma}_{j+1})$$

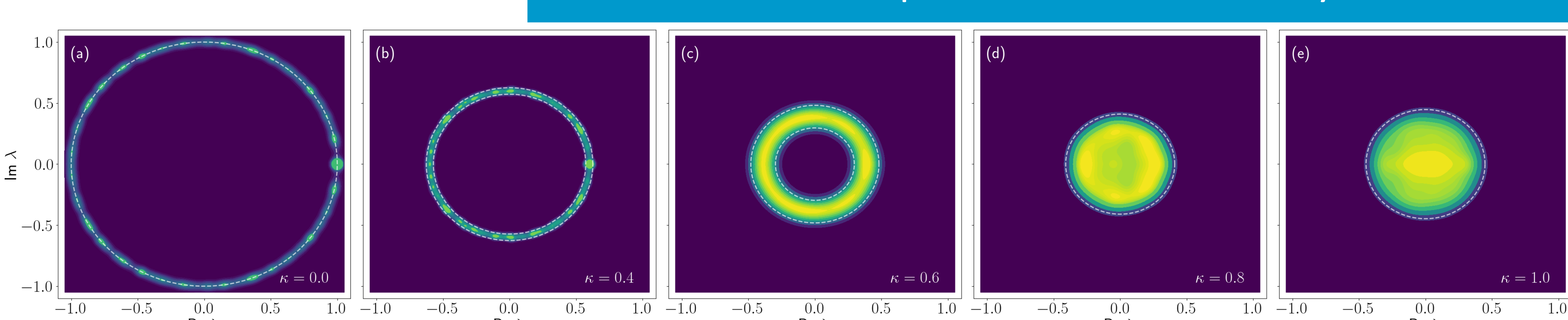
Free Fermions
Quadratic Hamiltonian written in the many-body spin basis

$$U_{FF} = e^{-iH_{FF}}$$

Clifford
Uniformly sample unitary from the L-qubit Clifford group

$$\{CNOT, H, P\}$$

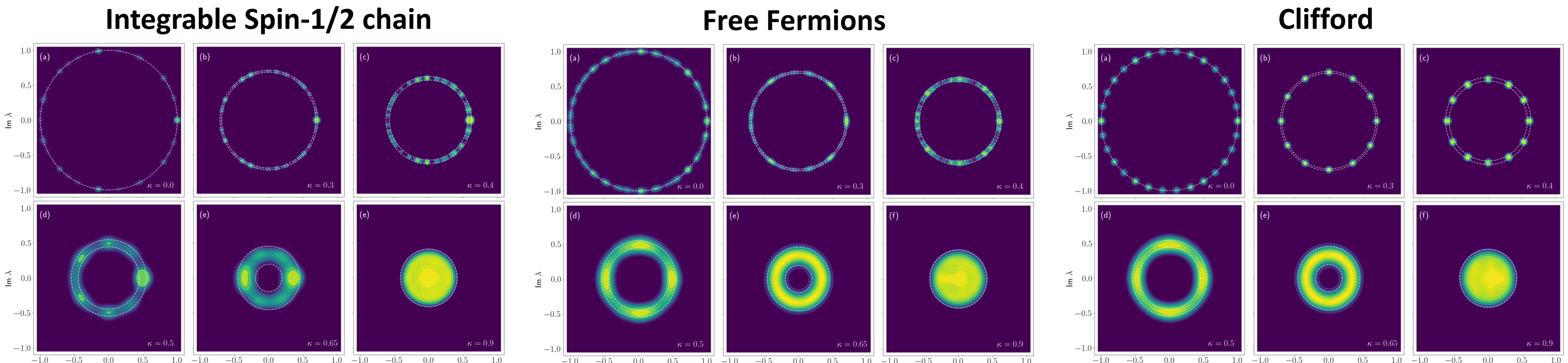
Map with a Chaotic Unitary



- **(a)** Distribution around unit circle;
- **(b) - (c)** As dissipation increases a ring forms;
- **(d)** For high enough κ, there is a transition from ring to disk;
- **(e)** Maximum dissipation ring with radius $1/\sqrt{r}$.

Map with an Integrable Unitary

Integrable Spin-1/2 chain **Free Fermions** **Clifford**



- **(a)** Degenerate distribution around unit circle;
- **(b) - (d)** Clusters are formed in the ring;
- **(e)** For high enough κ, more difficult to identify clusters;
- **(f)** Ring to disk transition occurs roughly at the same value as before.

Conclusions

- Dissipation induces a **universal** annulus-to-disk transition around essentially the same value of κ **independently** of the **nature of *U***.
- Increasing dissipation **lifts** the eigenvalue **degeneracies** until the map becomes completely chaotic.
- **Symmetries** the unitary map translates into a notorious eigenvalue **clustering**.

Acknowledgments

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