UTS UNIVERSITY OF TECHNOLOGY SYDNEY

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Chancellor's Postdoctoral Research Fellowships

EQUS Australian Research Council Centre of Excellence for Engineered Quantum Systems

Algorithms for non-Markovian noise

Christina Giarmatzi

AIP 2022, Adelaide

Quantum — the open journal for quantum science   PAPERS   PERSPECTIVES

Witnessing quantum memory in non-Markovian processes

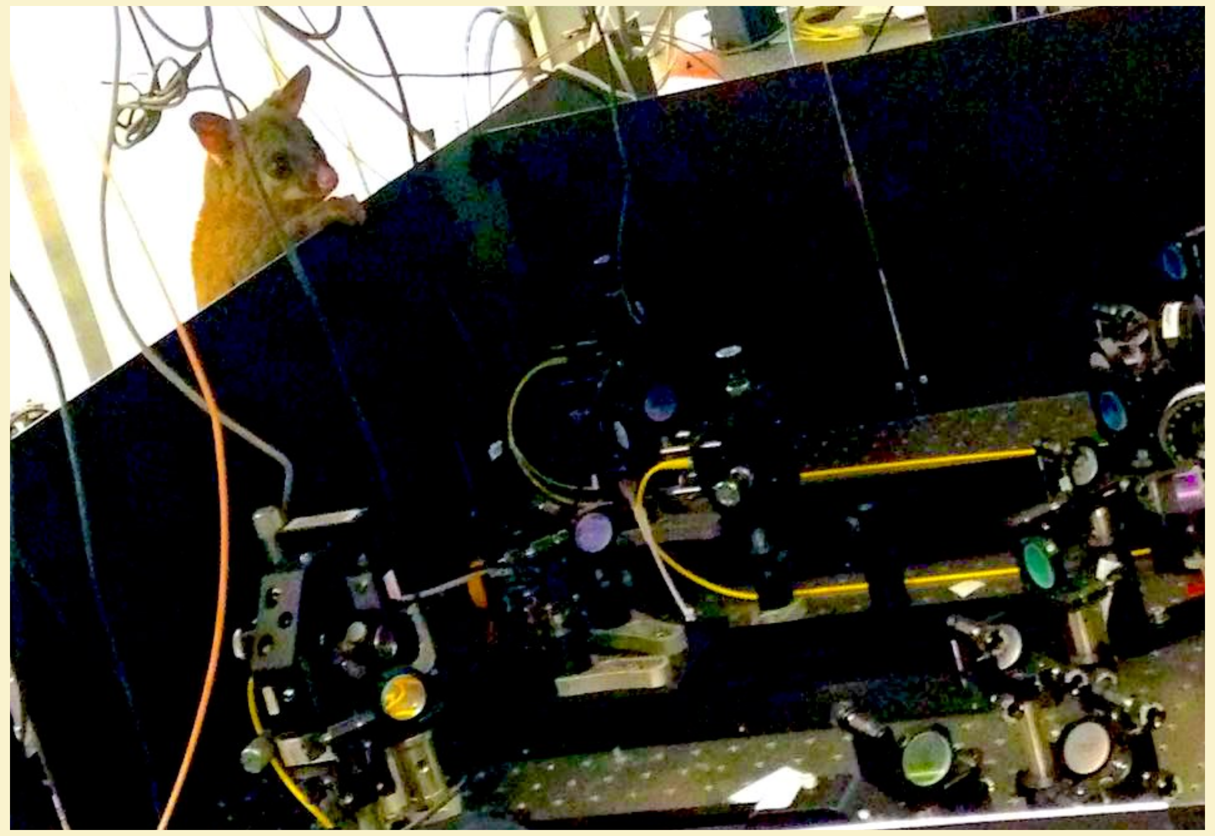
Christina Giarmatzi[1,2] and Fabio Costa[1]

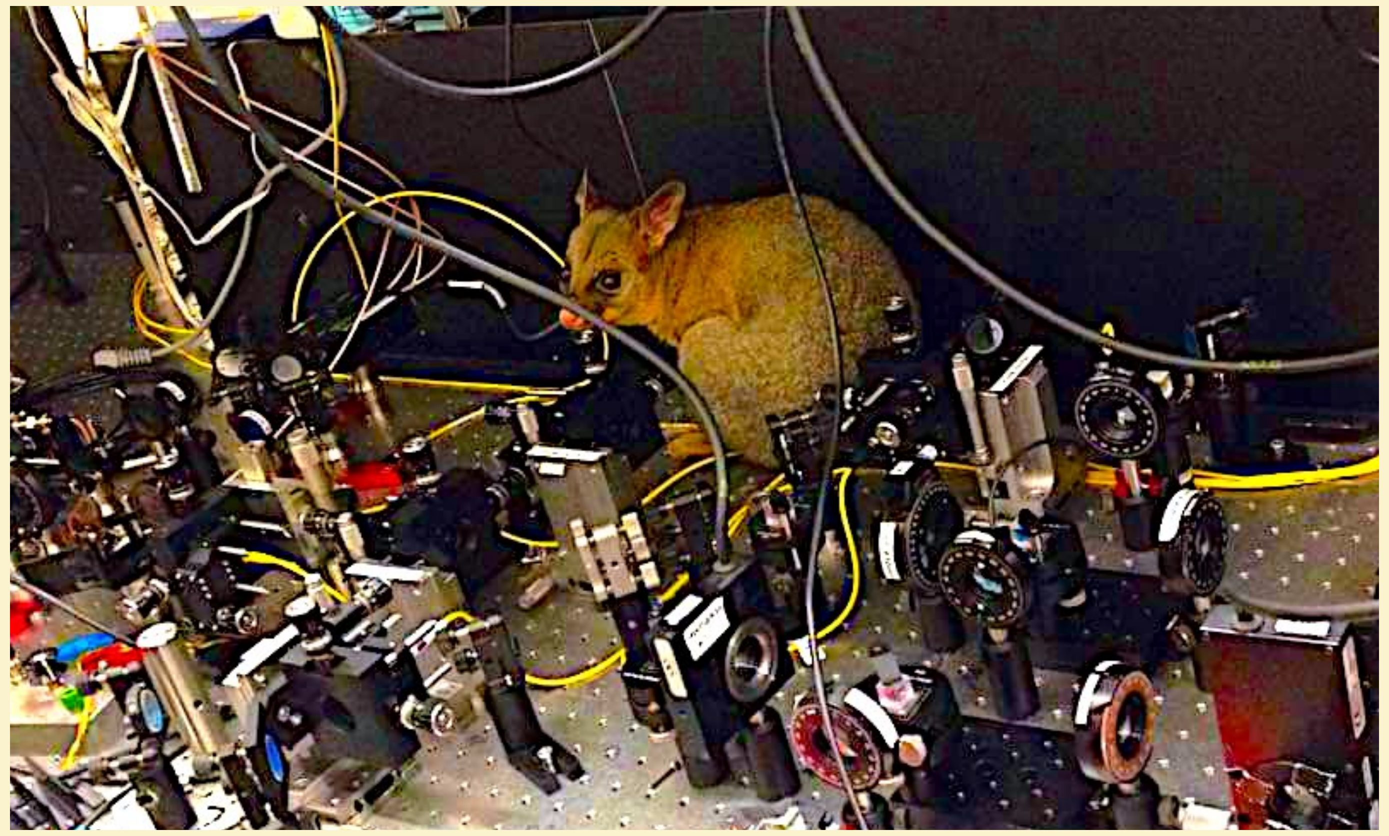
Percentile in Subject Area
91.75

Motivation

Quantum noise is bad

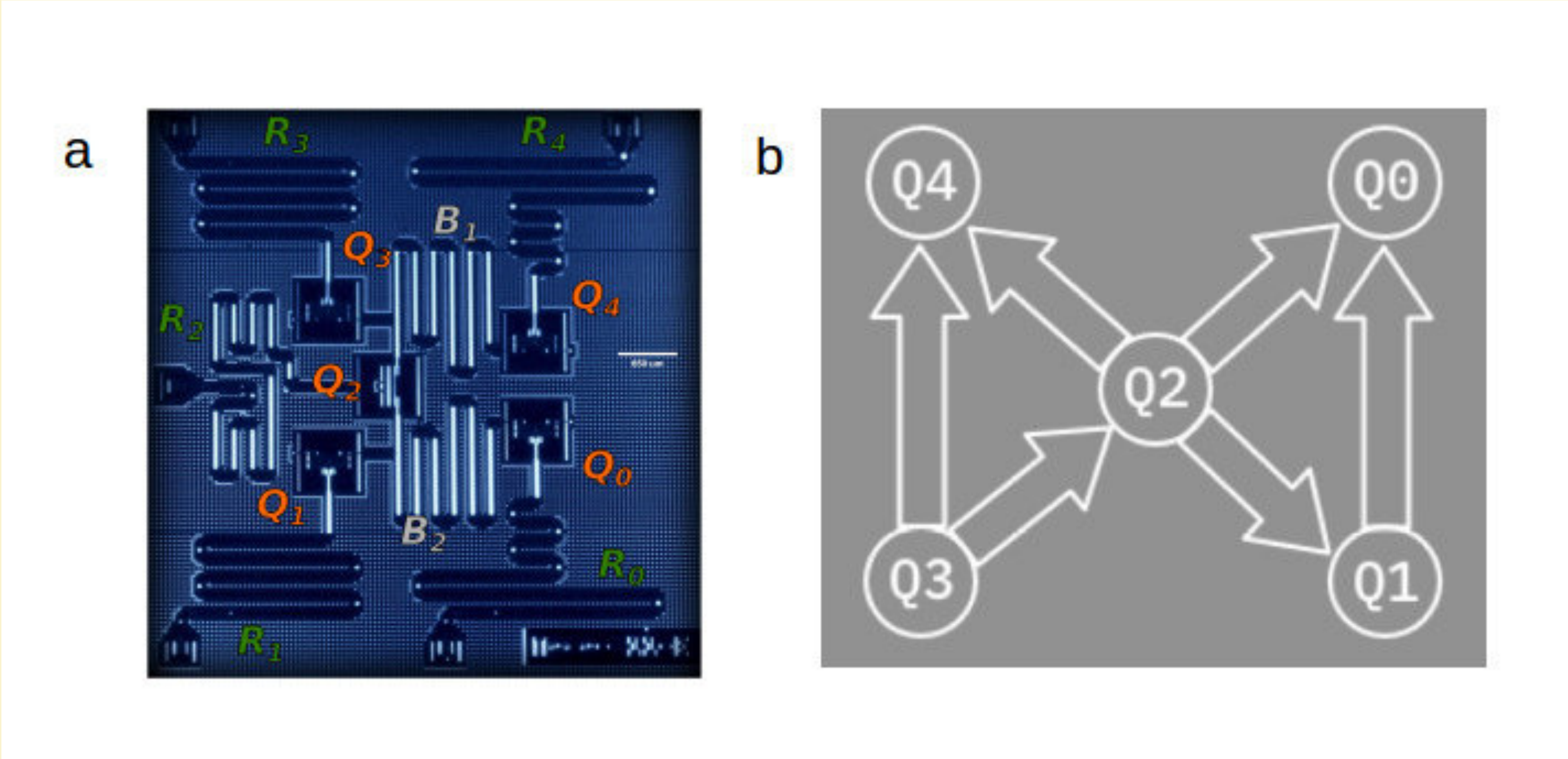
UQ - Andrew White's lab



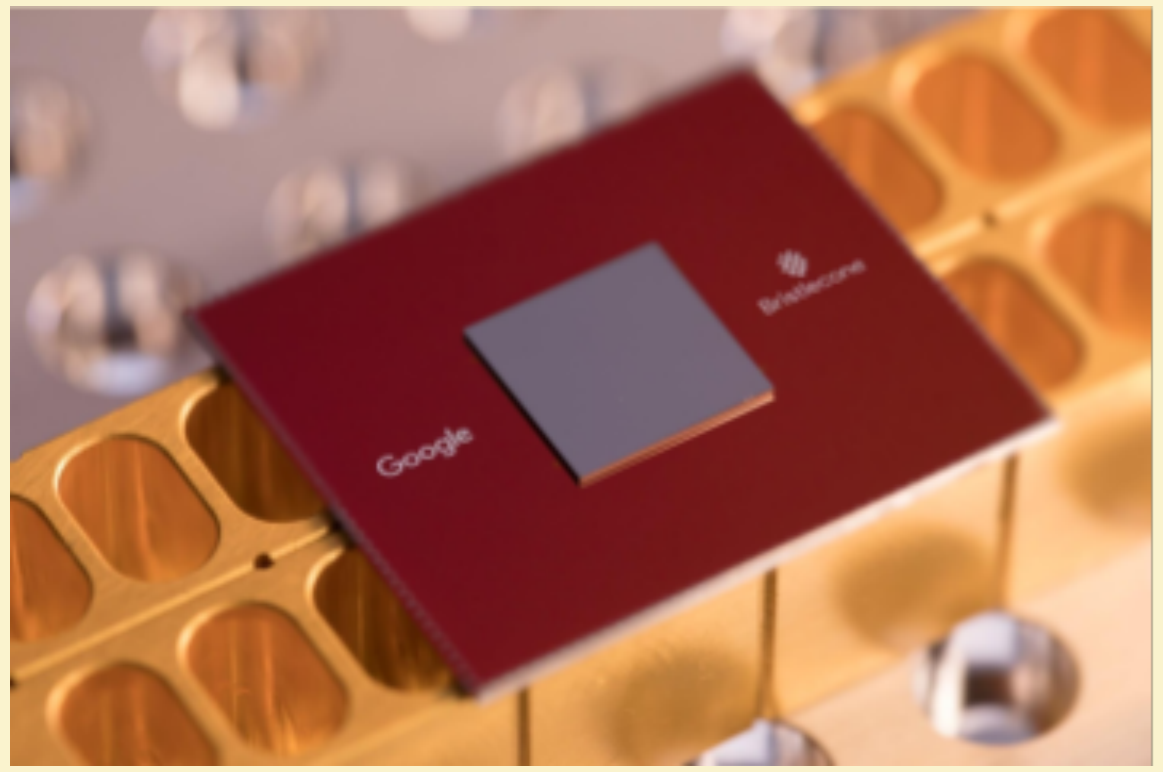


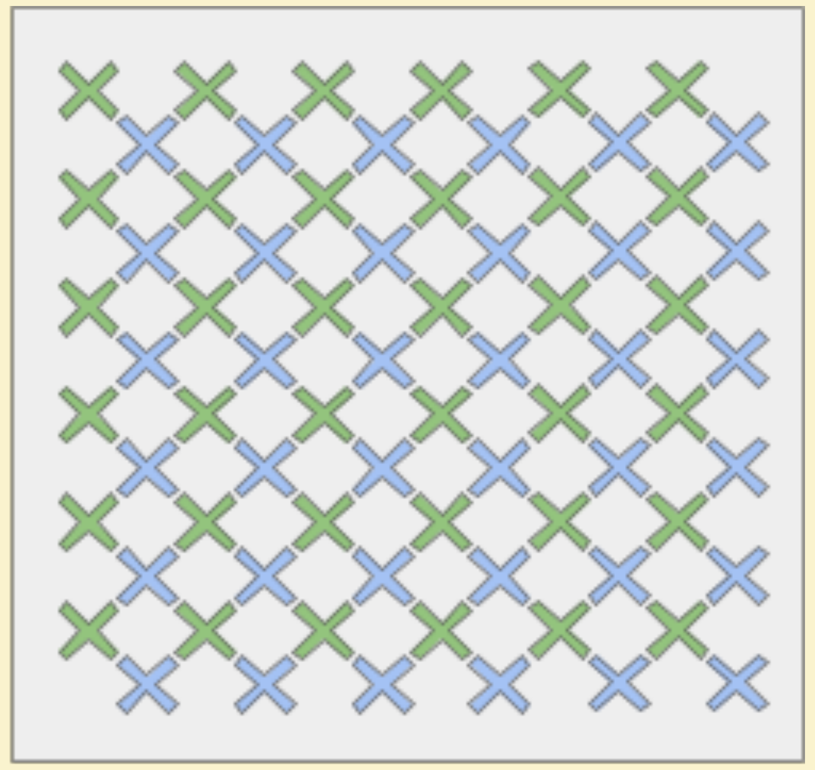
Quantum noise is quantum

ibmqx4

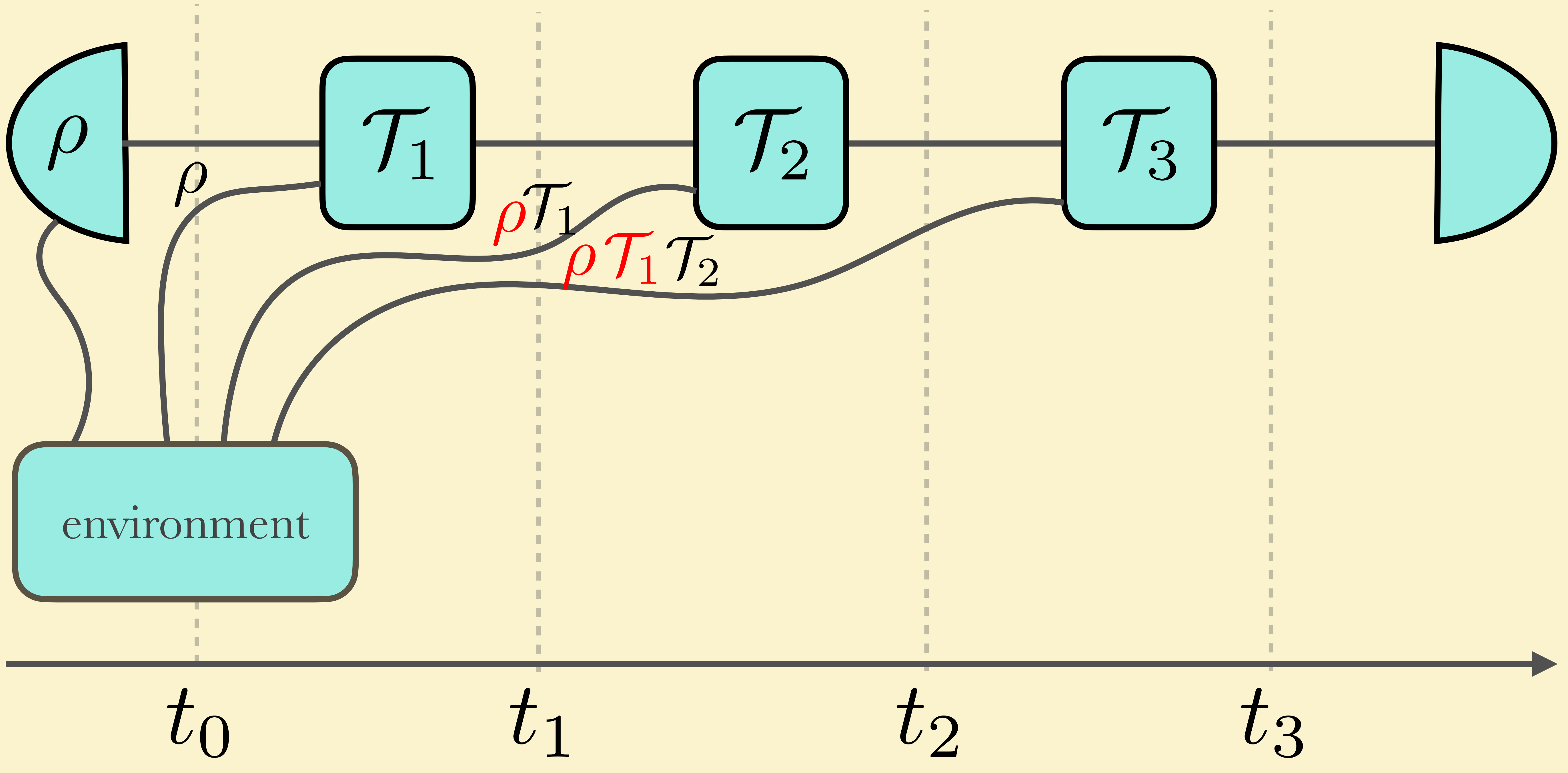


Sycamore



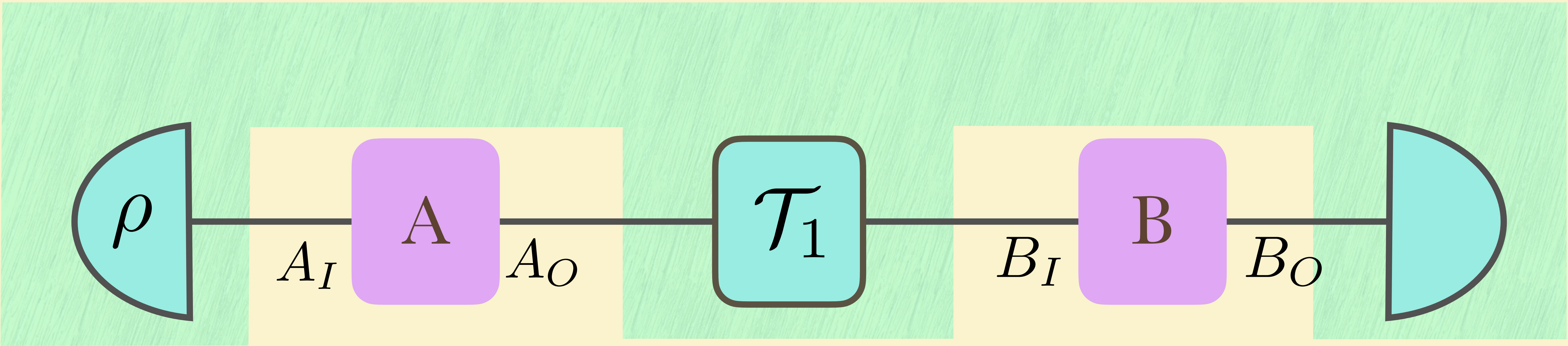


Open quantum systems



	Quantum description		Classical limit
Single time	$\rho(t_0), \rho(t_1), \rho(t_2), \rho(t_3)$	$\longrightarrow$	$p(X_{t_0}), p(X_{t_1}), p(X_{t_2}), p(X_{t_3})$
Two times	Dynamical maps	$\longrightarrow$	$p(X_{t_1}\vert X_{t_0}),\ p(X_{t_2}\vert X_{t_1}),\ p(X_{t_3}\vert X_{t_2})$
Multi-time	**???**	$\longrightarrow$	$p(X_{t_0}, X_{t_1}, X_{t_2}, X_{t_3})$

Process matrix



Result $p(o^A, o^B) = \mathrm{Tr}(W^{A_I A_O B_I B_O} M^{A_I A_O} \otimes M^{B_I B_O})$

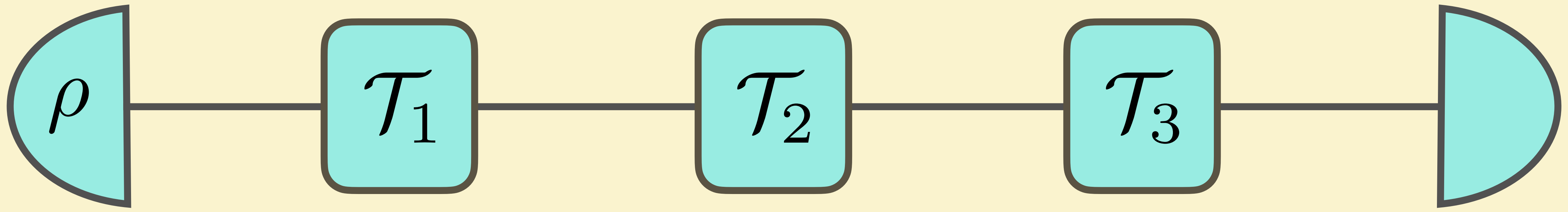
probabilities — environment — operations

O. Oreshkov and C. Giarmatzi, "Causal and causally separable processes", *New Journal of Physics* ***18****, 093020 (2016)*

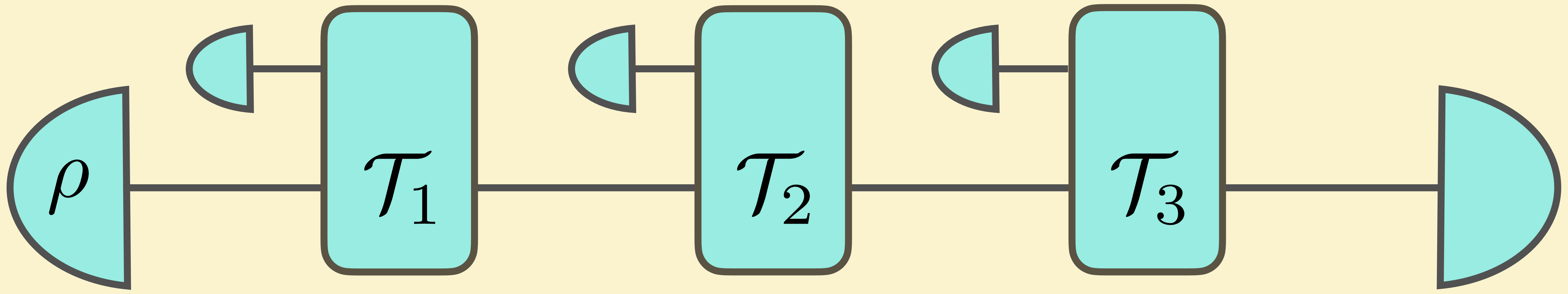
O. Oreshkov, F. Costa, Č. Brukner, "Quantum correlations with no causal order", Nat. Commun. **3** 1092 (2012)

Markovian process

Case 1: no noise

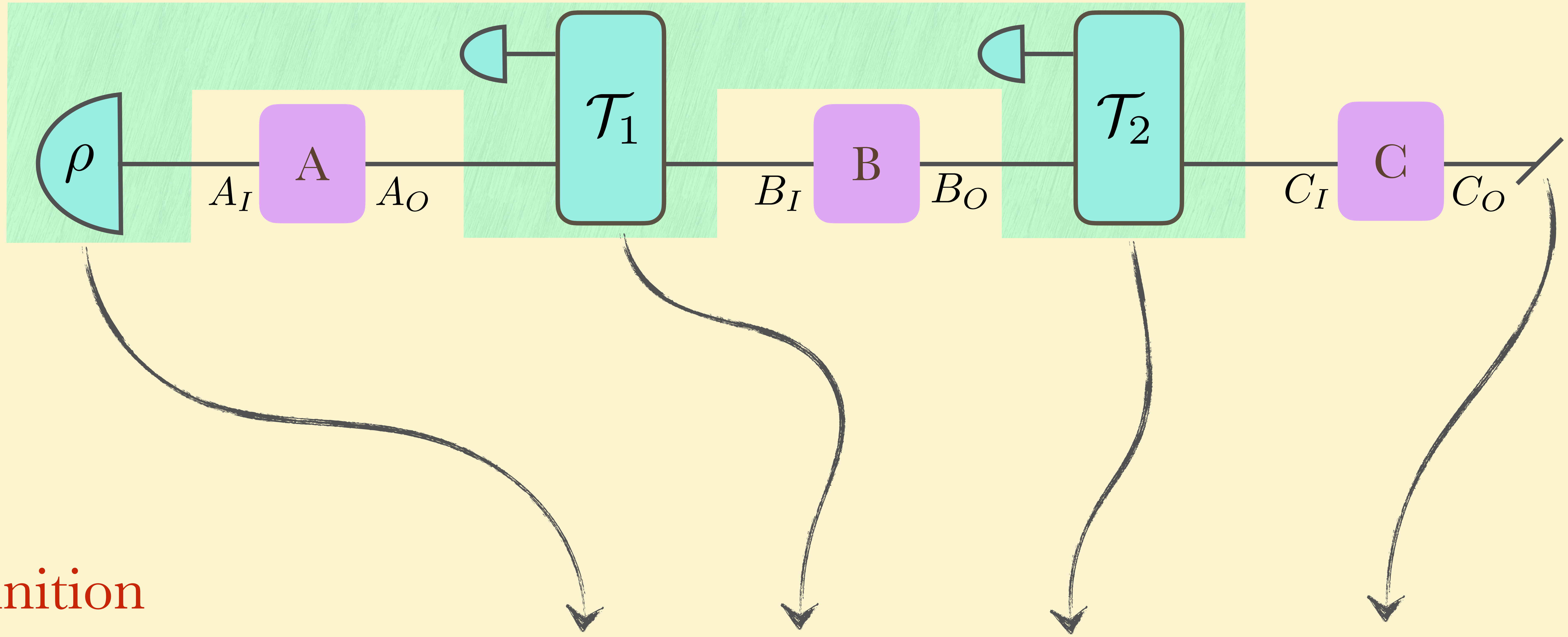


Case 2: Markovian noise



G. Lindblad, *"Non-Markovian quantum stochastic processes and their entropy"*, *Comm. Math. Phys. 65, 281 (1979)*
L. Accardi, A. Frigerio, and J.T. Lewis, *"Quantum stochastic processes", Publications of the Research Institute for Mathematical Sciences 18, 97 (1982)*
F. A. Pollock *et al.*, *"Non-Markovian quantum processes: Complete framework and efficient characterization", Physical Review A 97, 012127 (2018)*
C. Giarmatzi and F. Costa, *"Witnessing quantum memory in non-Markovian processes", Quantum 5, 440* (2021)

Markovian process matrix



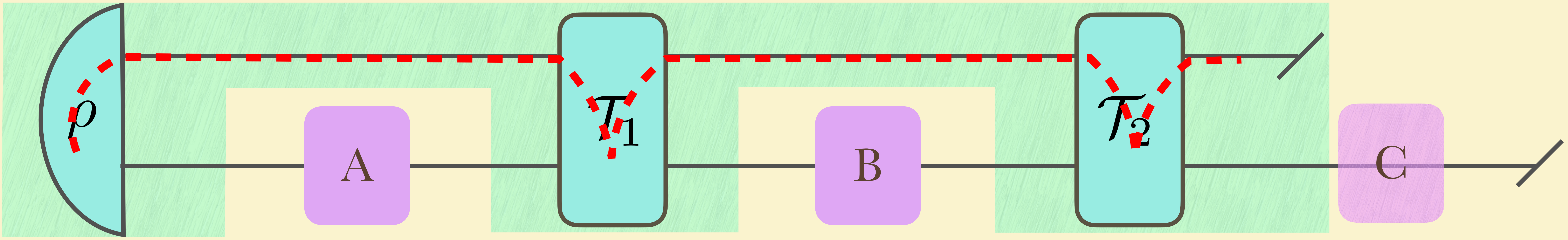
Definition

$$W_{\mathrm{M}}^{ABC} = \rho^{A_I} \otimes T_1^{A_O B_I} \otimes T_2^{B_O C_I} \otimes \mathbb{1}^{C_O}$$

$p(o^A, o^B) = \mathrm{Tr}(W^{A_I A_O B_I B_O} M^{A_I A_O} \otimes M^{B_I B_O})$

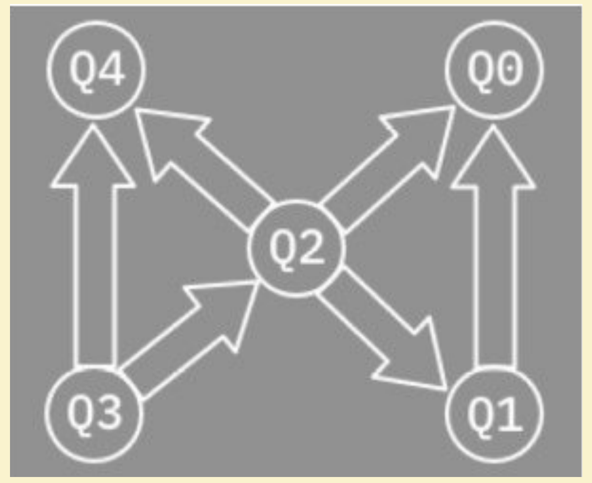
Non-Markovian process

There is a memory that carries correlations

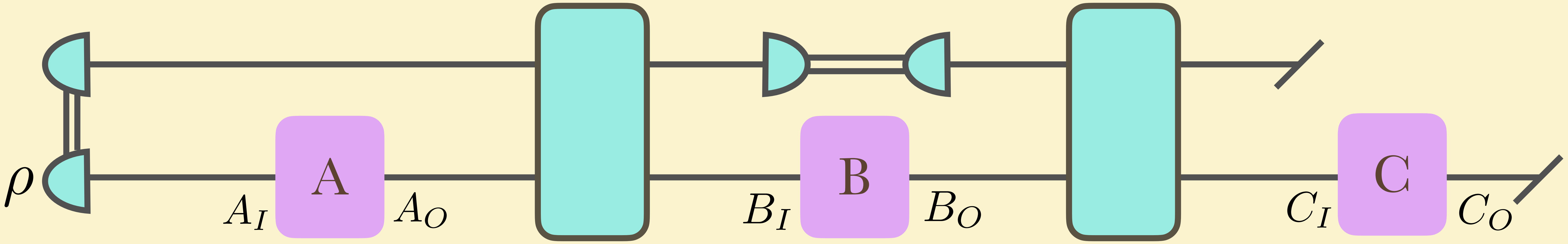


Is it classical?

Or quantum?



Classical memory

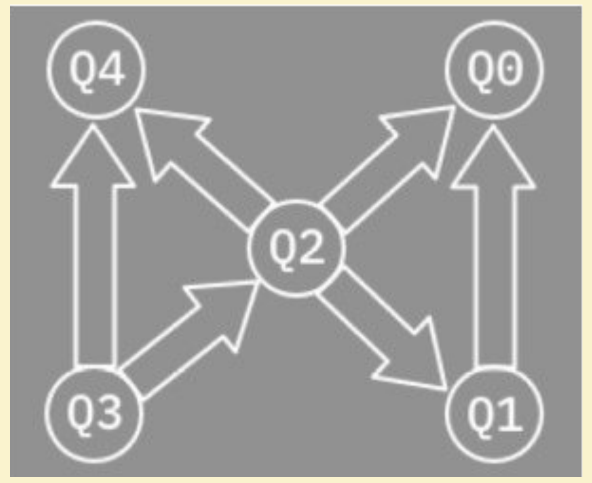


Classical information

The environment obtains classical info and can affect future interactions

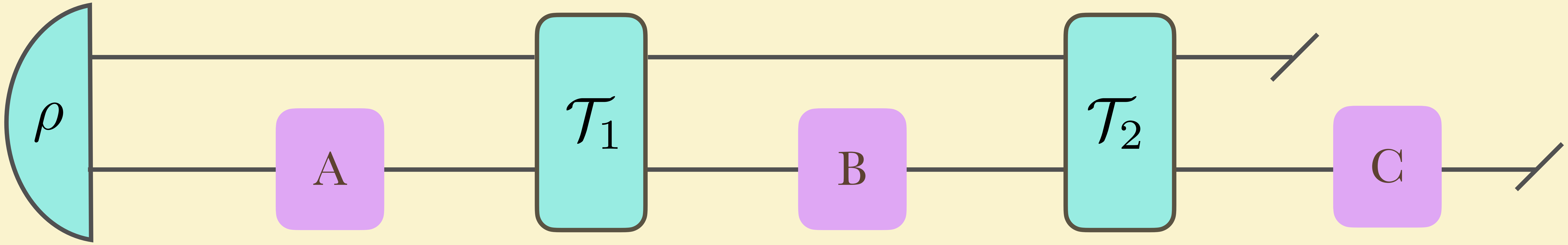
It can be written

$$W_{Cl}^{ABC} = \sum_j \rho_j^{A_I} \otimes T_j^{A_O B_I} \otimes N_j^{B_O C_I} \otimes \mathbb{1}^{C_O}$$

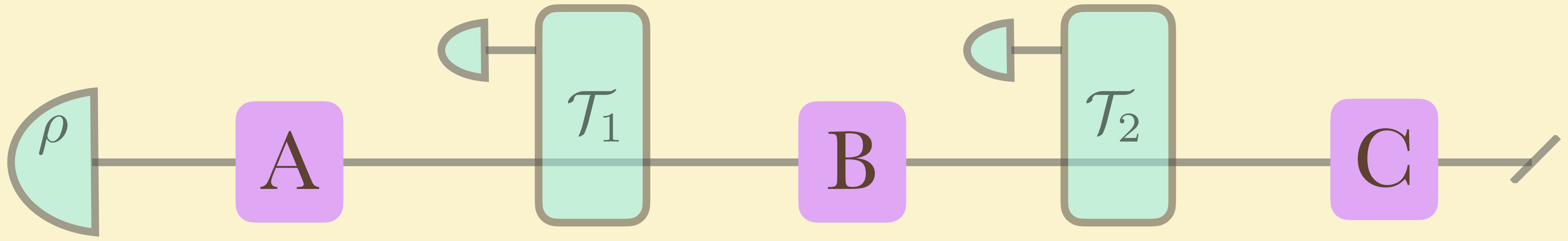


Quantum memory

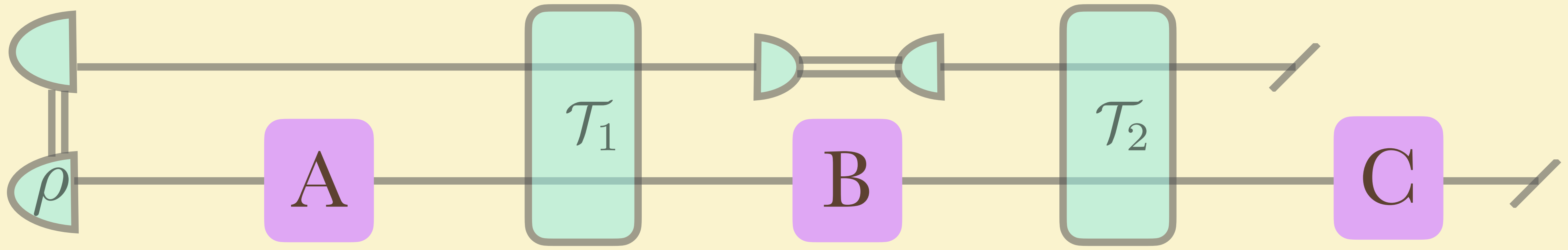
Everything else!



Not Markovian



Not with classical memory



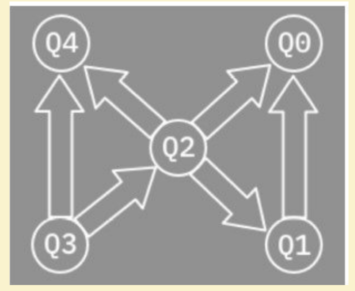
Detecting quantum memory

classical memory

$$W_{Cl}^{ABC} = \sum_j \rho_j^{A_I} \otimes T_j^{A_O B_I} \otimes N_j^{B_O C_I} \otimes \mathbb{1}^{C_O}$$

Observation: Separable states

Our main result:



Detecting

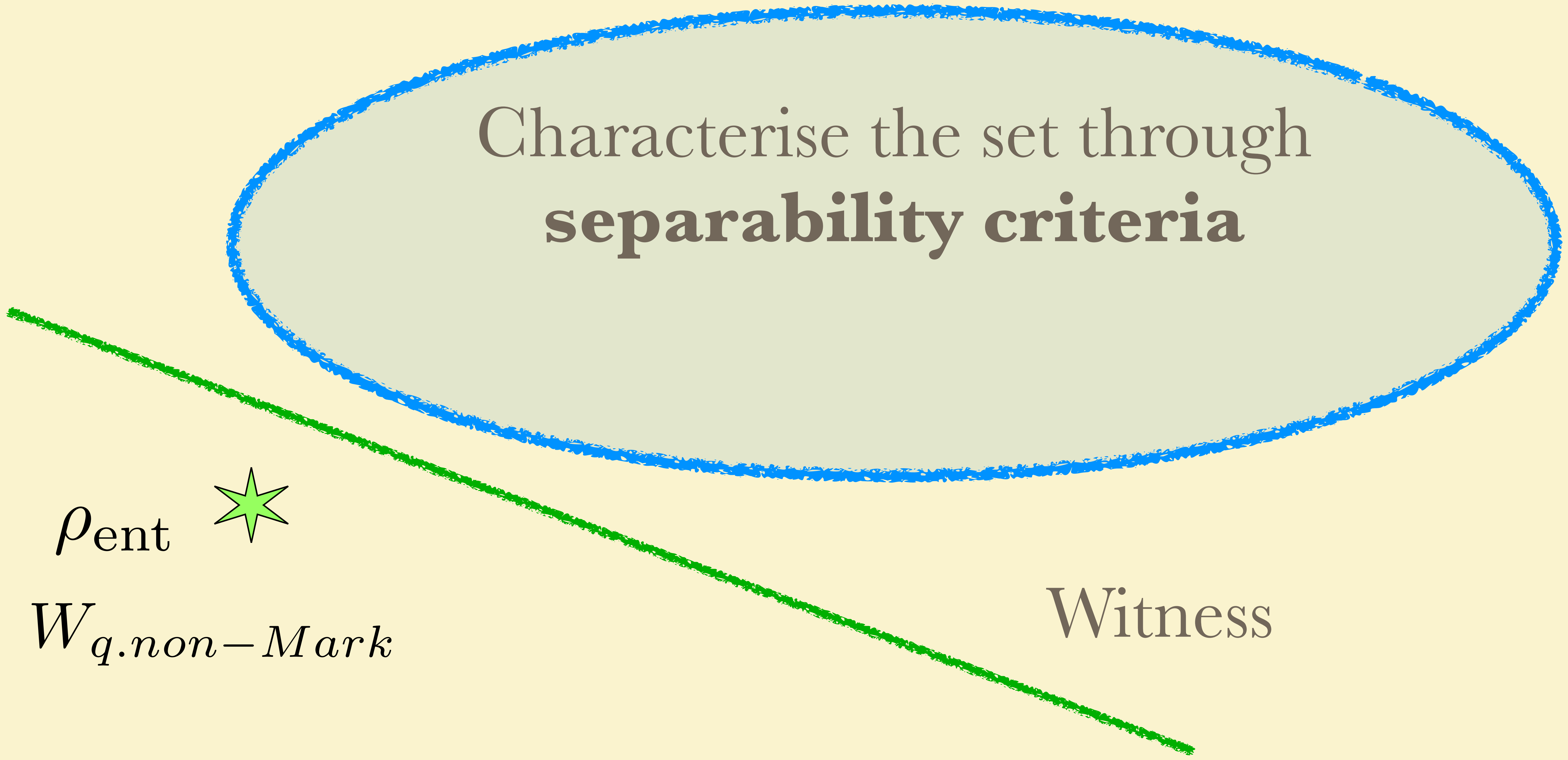
Process with quantum memory

Detecting

Entangled state

Detecting entanglement

1 way

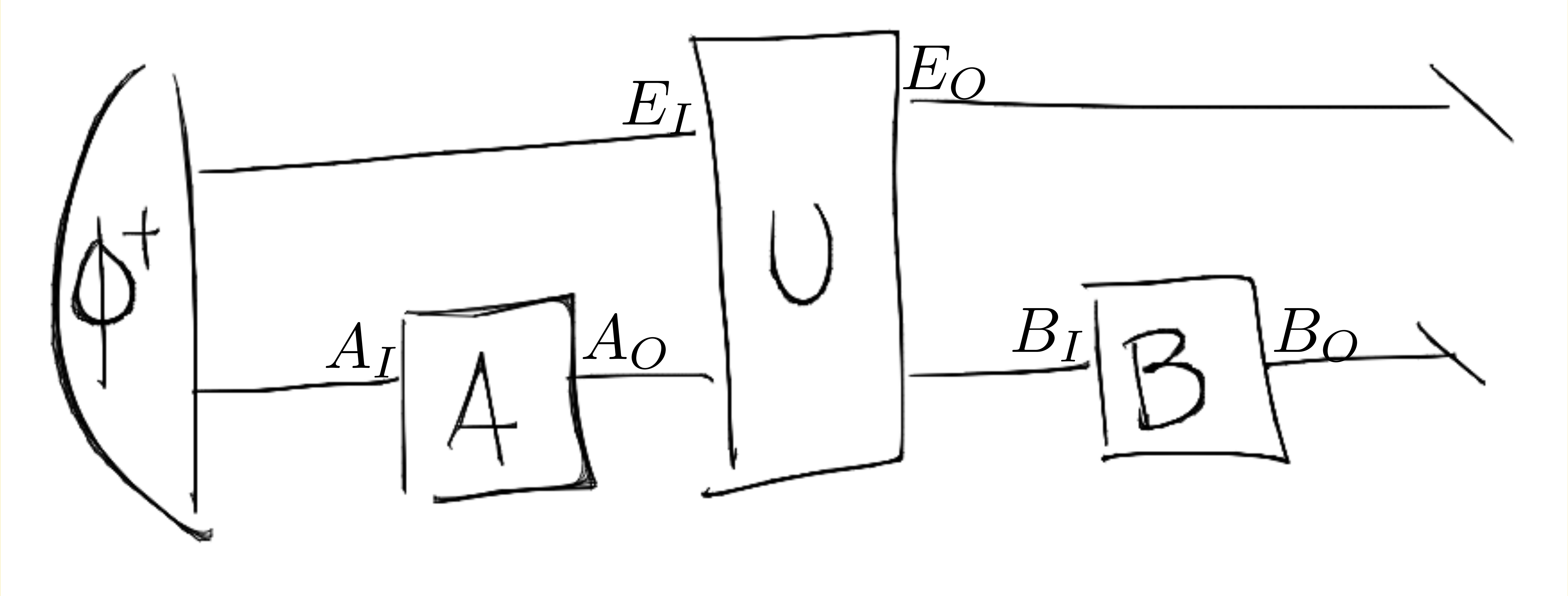


Witness Z

$$\mathrm{Tr}(Z\rho_{\text{ent}}) < 0$$

$$\mathrm{Tr}(ZW_{q.non-Mark}) < 0$$

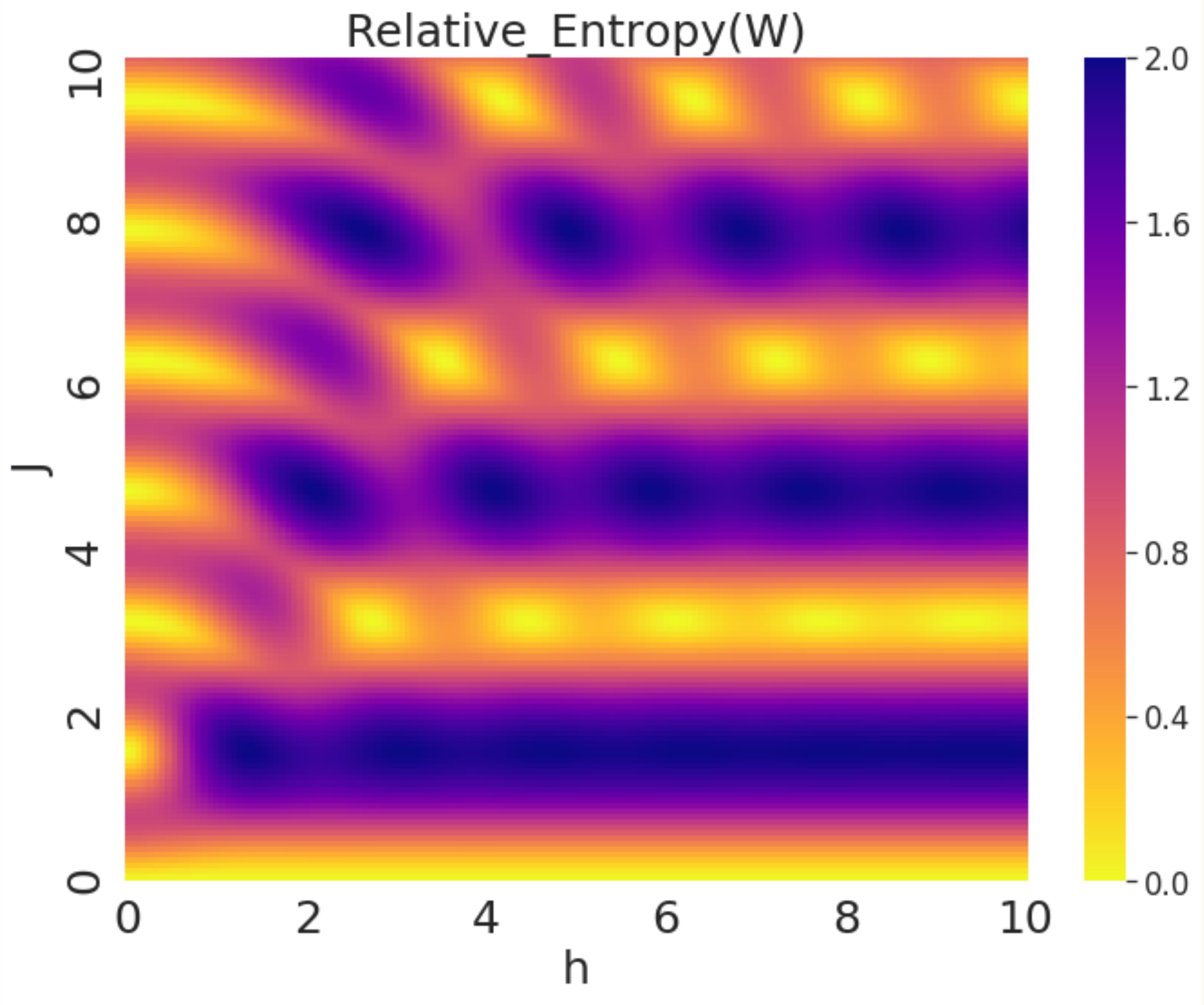
A process: Φ^+ and Ising model

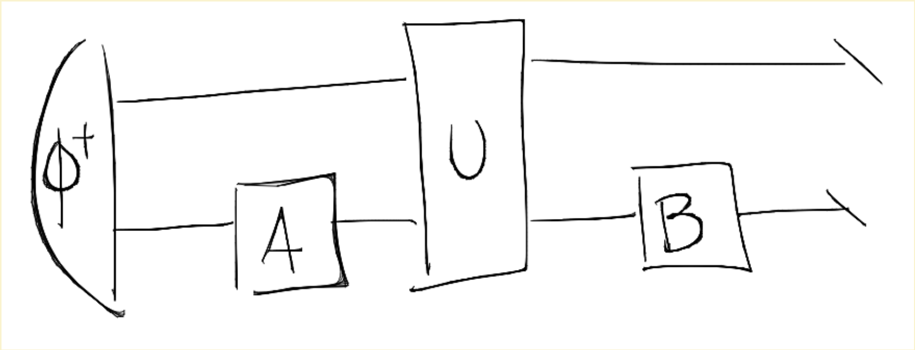


$\Phi = 1/\sqrt{2}(|00\rangle + |11\rangle)$ $\quad U(J,h,t) = e^{-iH(J,h)t}$ $\quad \mathcal{H} = -JXX - h(Z\mathcal{I} + \mathcal{I}Z)$

$$W^{A_I A_O B_I}(J,h,t) = \mathrm{Tr}_{E_O}[[U(J,h,t)]]$$

Estimate Markovianity

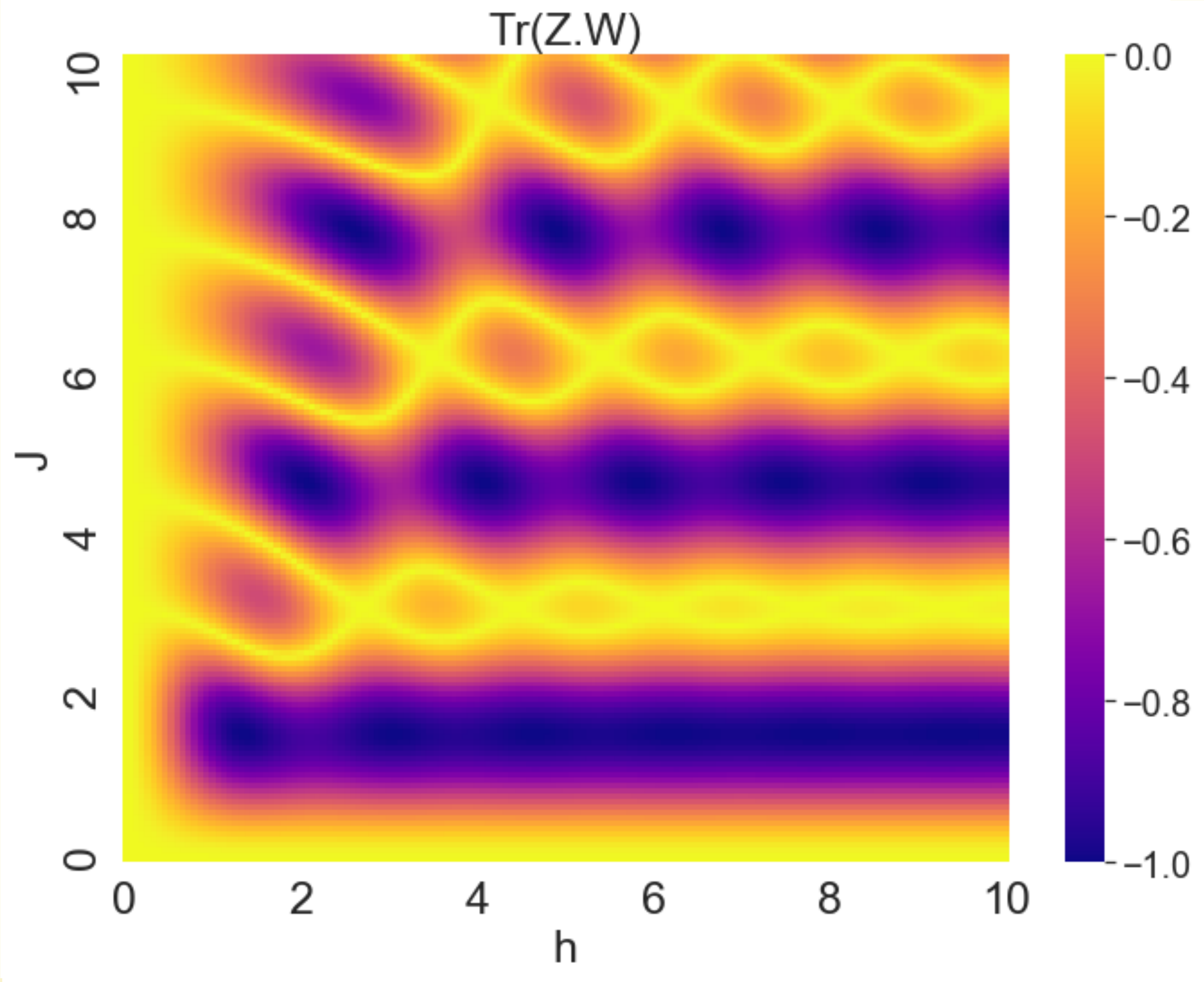


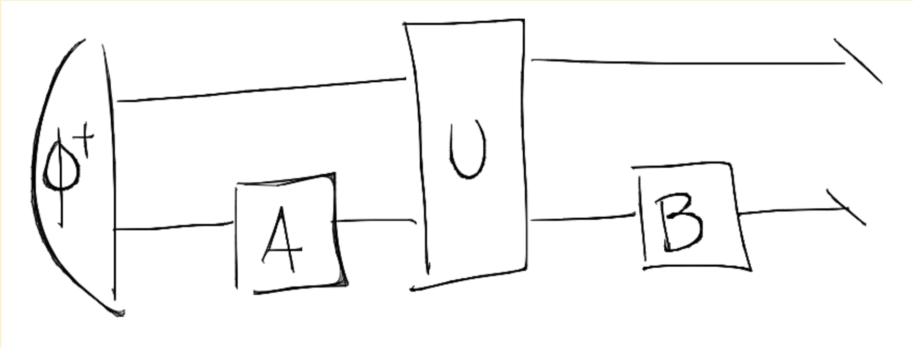


$$t = 1$$

$$W^{A_I A_O B_I}(J, h)$$

Witness quantum memory





$$t = 1$$

$$W^{A_I A_O B_I}(J, h)$$

PPT

Quantum
the open journal for quantum science

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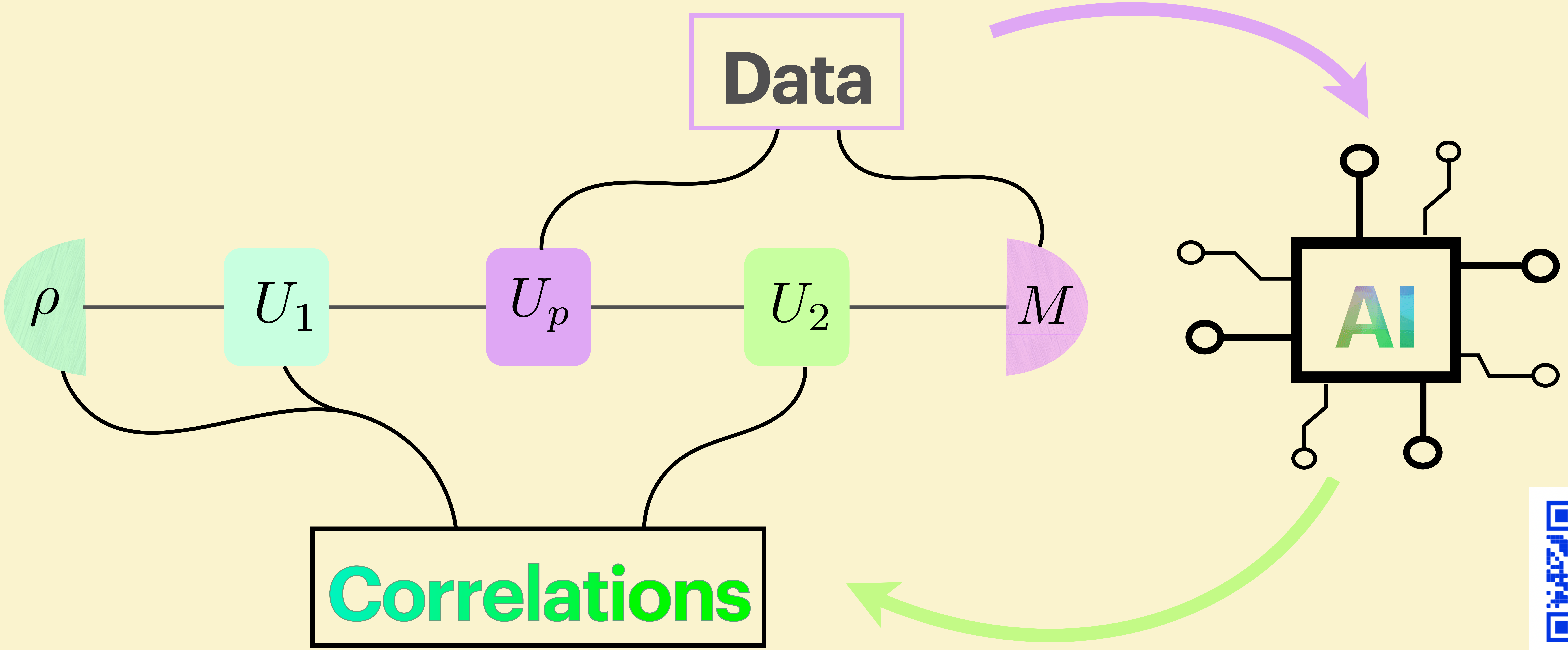
A photonics experiment



Editors' Suggestion

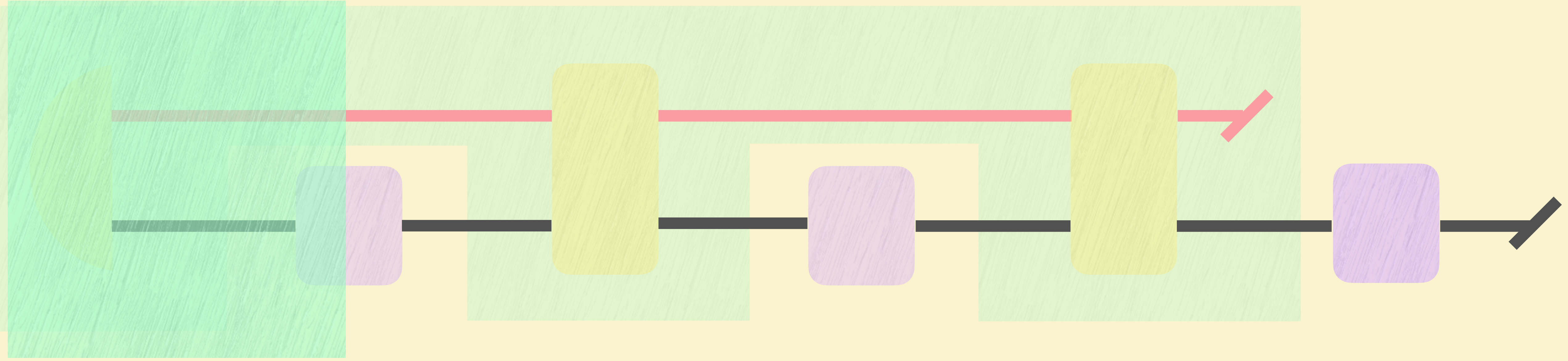
Experimental characterization of a non-Markovian quantum process

K. Goswami, C. Giarmatzi, C. Monterola, S. Shrapnel, J. Romero, and F. Costa
Phys. Rev. A **104**, 022432 – Published 26 August 2021

New results!

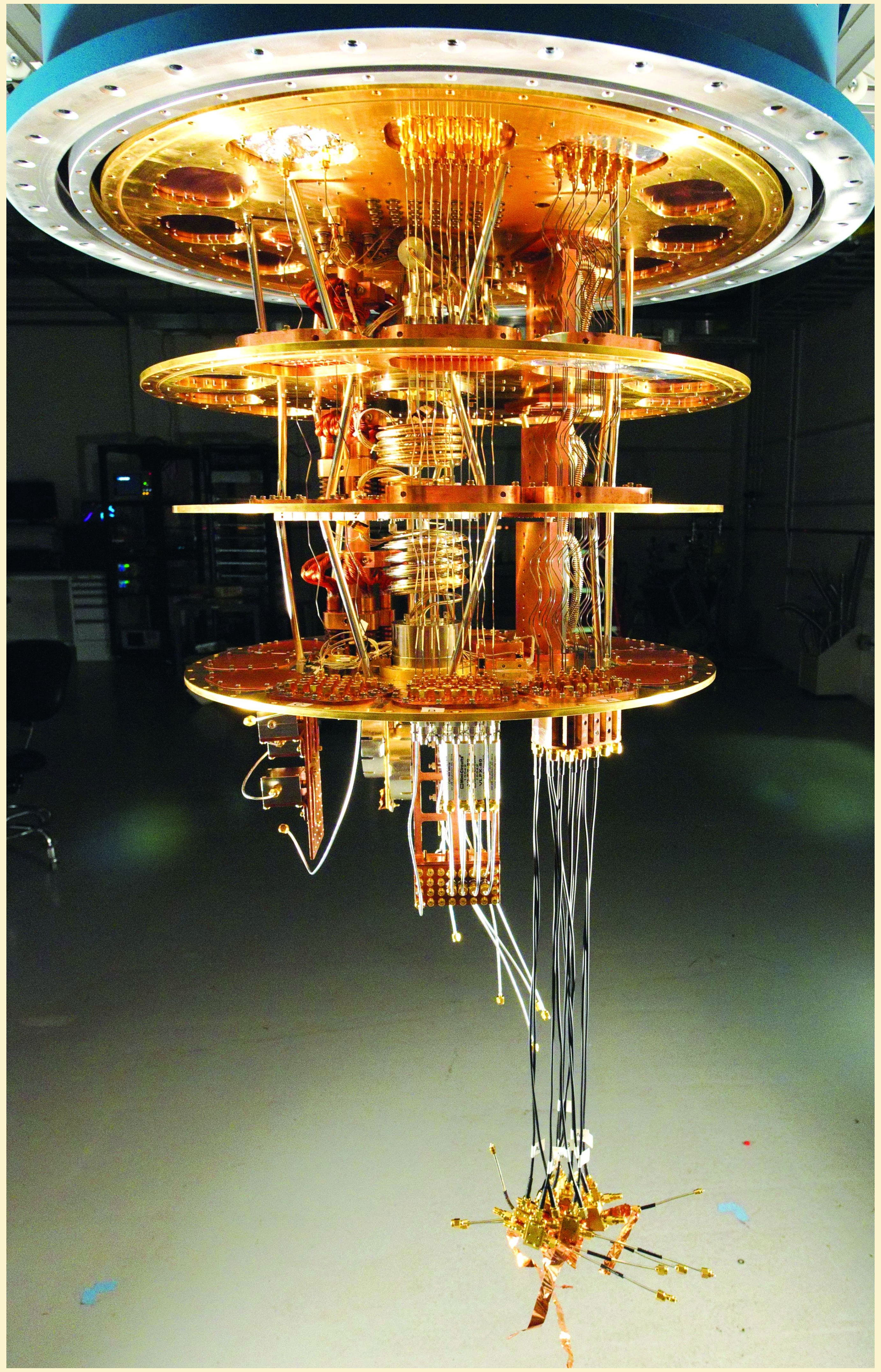
Full multi-time process tomography

With superconducting qubits



	UQ: 5-qubit chip	IBM: ibm_perth 7-qubit chip
Measure of non-Markovian noise	0.633 ± 0.006	0.0843 ± 0.006
Measure of quantum non-Markovian noise	-0.055 ± 0.003	-0.0094 ± 0.003

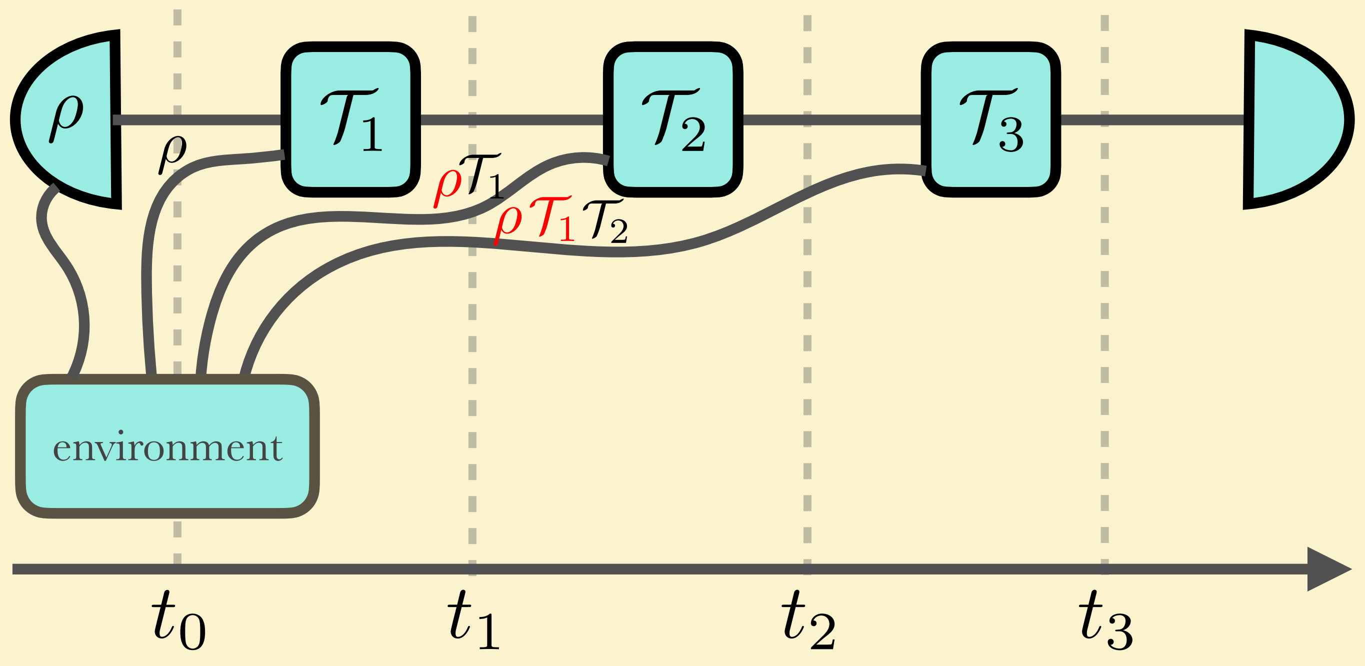
Outlook

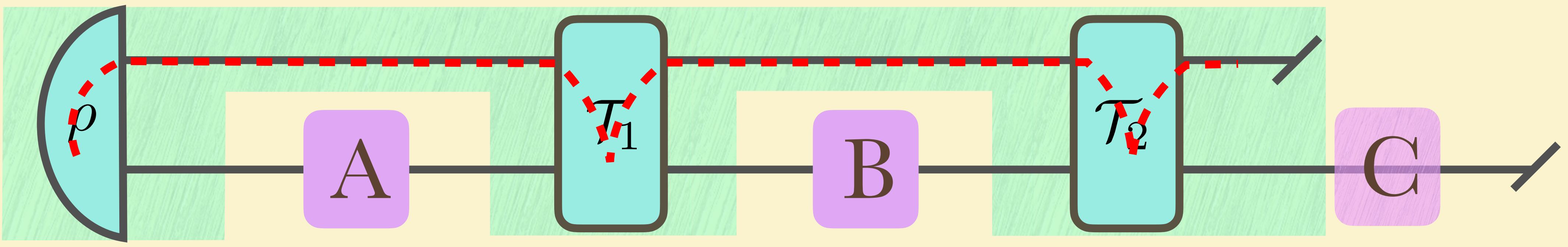


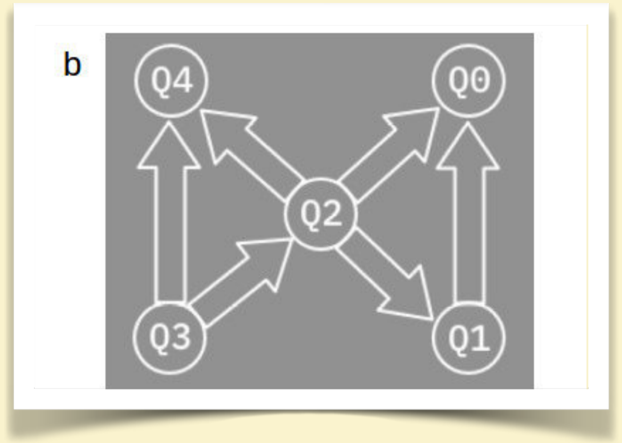
Detecting quantum memory in more quantum devices

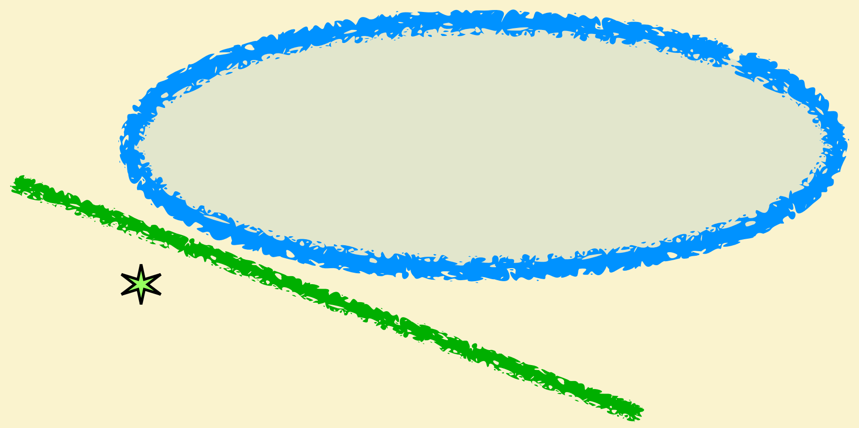
Tune parameters to eliminate it

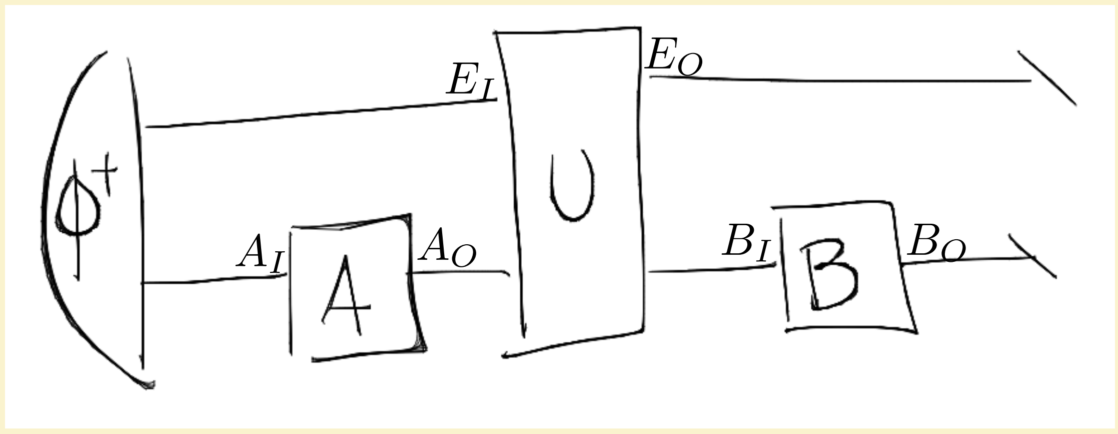
Summary

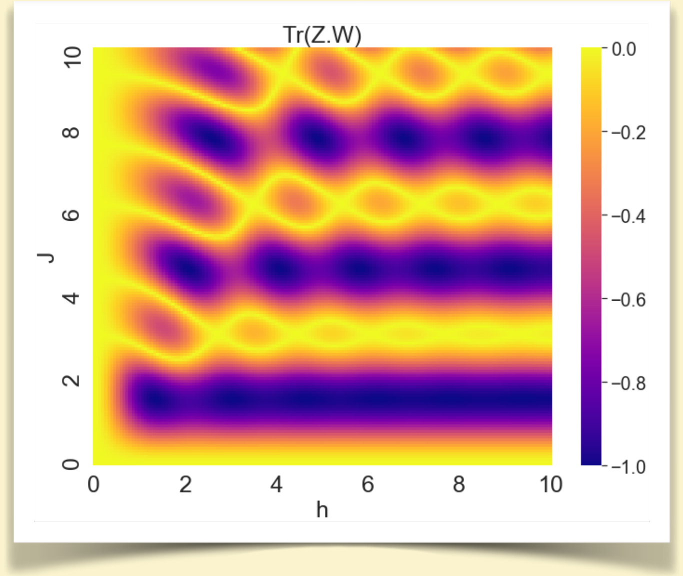


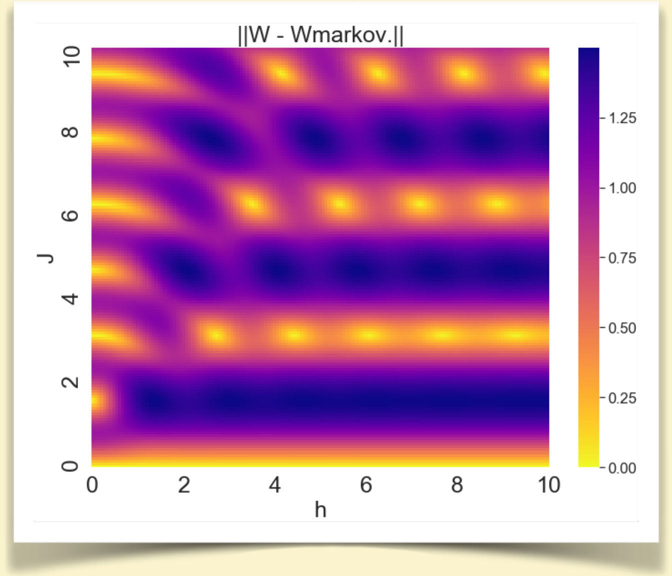


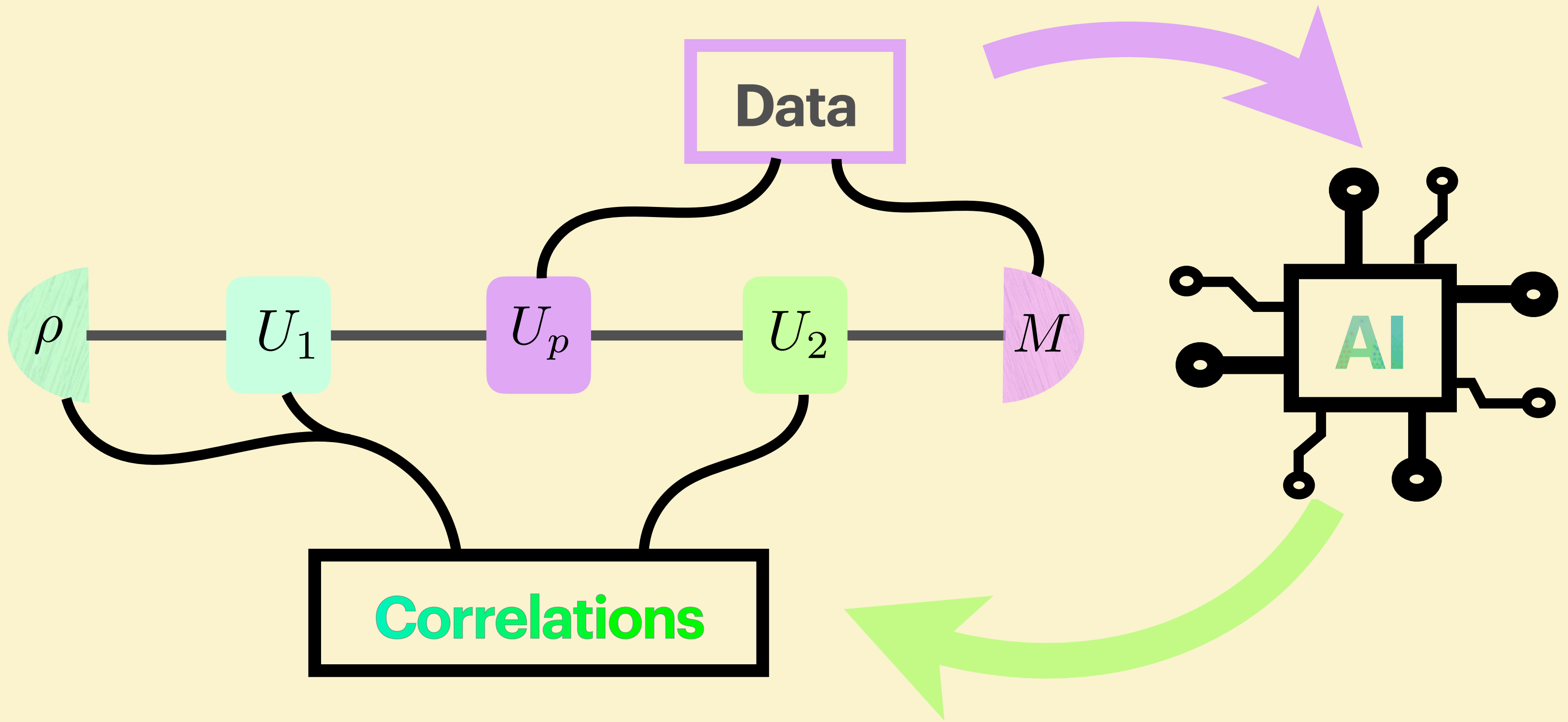








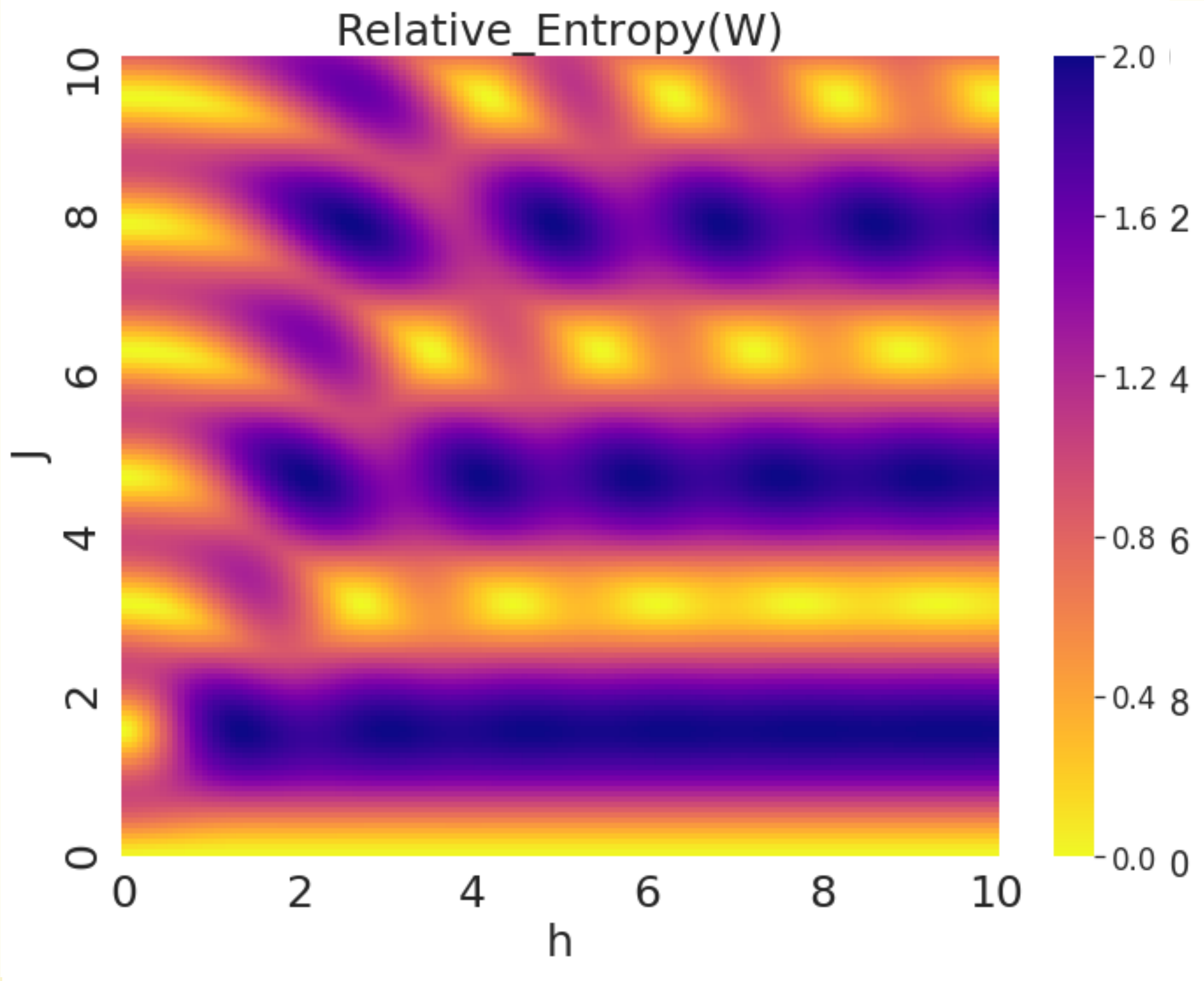


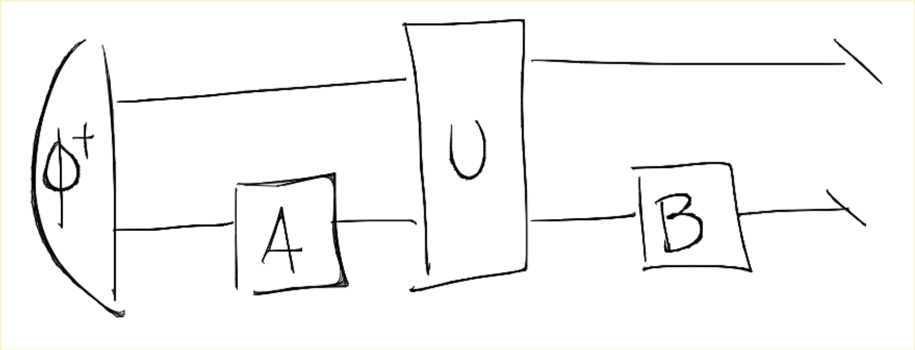


	UQ: 5-qubit chip	IBM: ibm_perth 7-qubit chip
Measure of non-Markovian noise	0.633±0.006 (562)	0.0843 ±0.006 (591)
Measure of quantum non-Markovian noise	-0.055 ±0.003 (259)	-0.0094 ±0.003 (257)


The End

Results - Markovianity





$$t = 1$$

$$W^{A_I A_O B_I}(J, h)$$

Definition of classical memory

$$W_{\mathrm{Cl}}^{A^1 \ldots A^n} = \sum_{\vec{x}} \bigotimes_{j=0}^{n-1} T_{x_j|\vec{x}_{|j}}^{A_O^j A_I^{j+1}} .$$

CPTP map. Here, x_j denotes the classical information available at time t_j, while a_j denotes the information the environment acquires during the interaction.

Finding a witness

PPT-1

$$\rho_{sep}^{AB} \Rightarrow \rho^{T_A} > 0$$

Method 1

$$\rho^{T_A} < 0 \longrightarrow |\psi\rangle^{T_A} = \sum_i \epsilon_i E_i \qquad \exists j \ \ \epsilon_j < 0$$

$$\mathrm{Tr}(|E_j\rangle\langle E_j|\rho^{T_A}) = \epsilon_j < 0 \Rightarrow \mathrm{Tr}(|E_j\rangle\langle E_j|^{T_A}\rho) < 0$$

Witness !

Method 2

SemiDefinite Program

variable Z

minimize $\mathrm{Tr}(Z\rho)$ <0

subject to $\mathrm{Tr}\ Z = 1$

Output:

If optimal value < 0

Witness !

What to do with a witness

Operator Z, such that $\mathrm{Tr}(Z\rho) < 0$

state

process matrix

We don't know the ~~state.~~ process

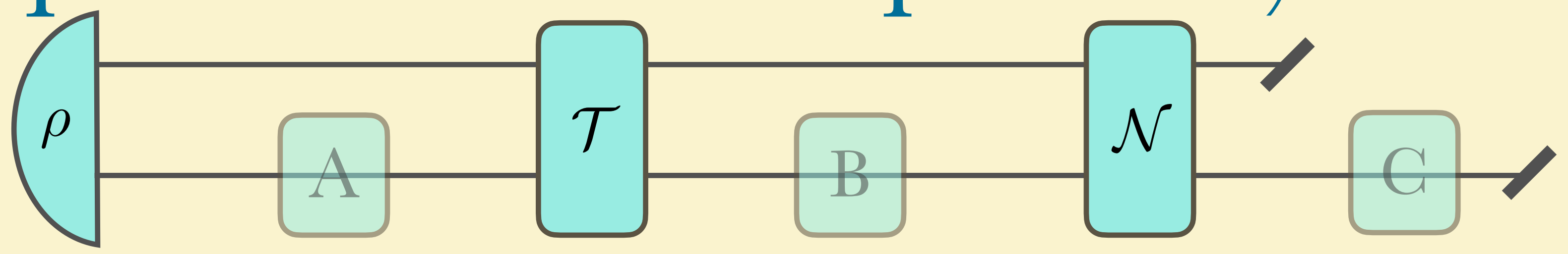
We don't want to do ~~tomography.~~ process tomography

We want to know if it ~~is entangled~~. has quantum memory

We make a guess ~~ρ' for ρ.~~ W' for W

Find a witness for ~~ρ~~′ (some operator). W' (operations in the process)

Apply operator, get negative exp. value,



=>Detect ~~entanglement in ρ.~~ quantum memory in W ! ! !