Dimension Reduction for Quantum Stochastic Modelling

Speaker: ***Chengran Yang***,
Collaborators: Mile Gu, Jayne Thompson, Thomas Elliot, Andrew Garner, Kangda Wu, Guoyong Xiang, Oscar Dahlsten, Feiyang Liu, Nora Tischlerm, …

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: Main Auditorium, CERN

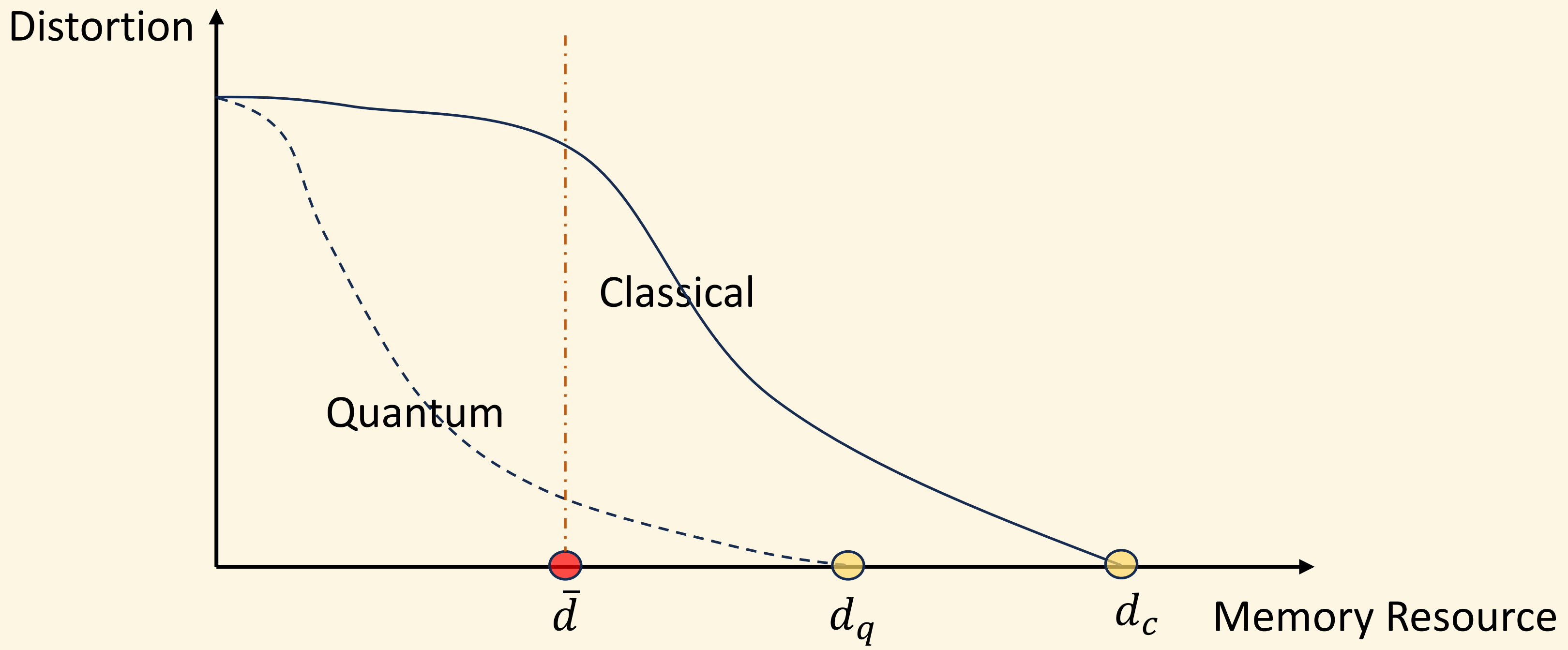
Centre for Quantum Technologies
National University of Singapore

A small game

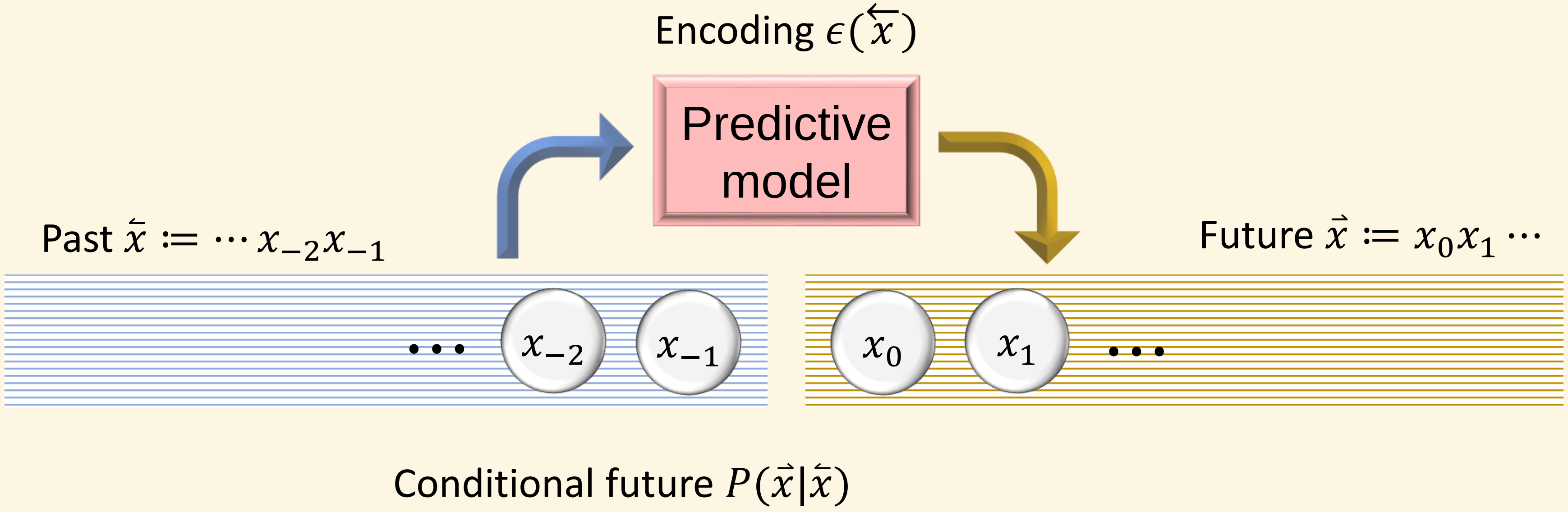
What will the main character?

Will the main character like quantum machine learning?

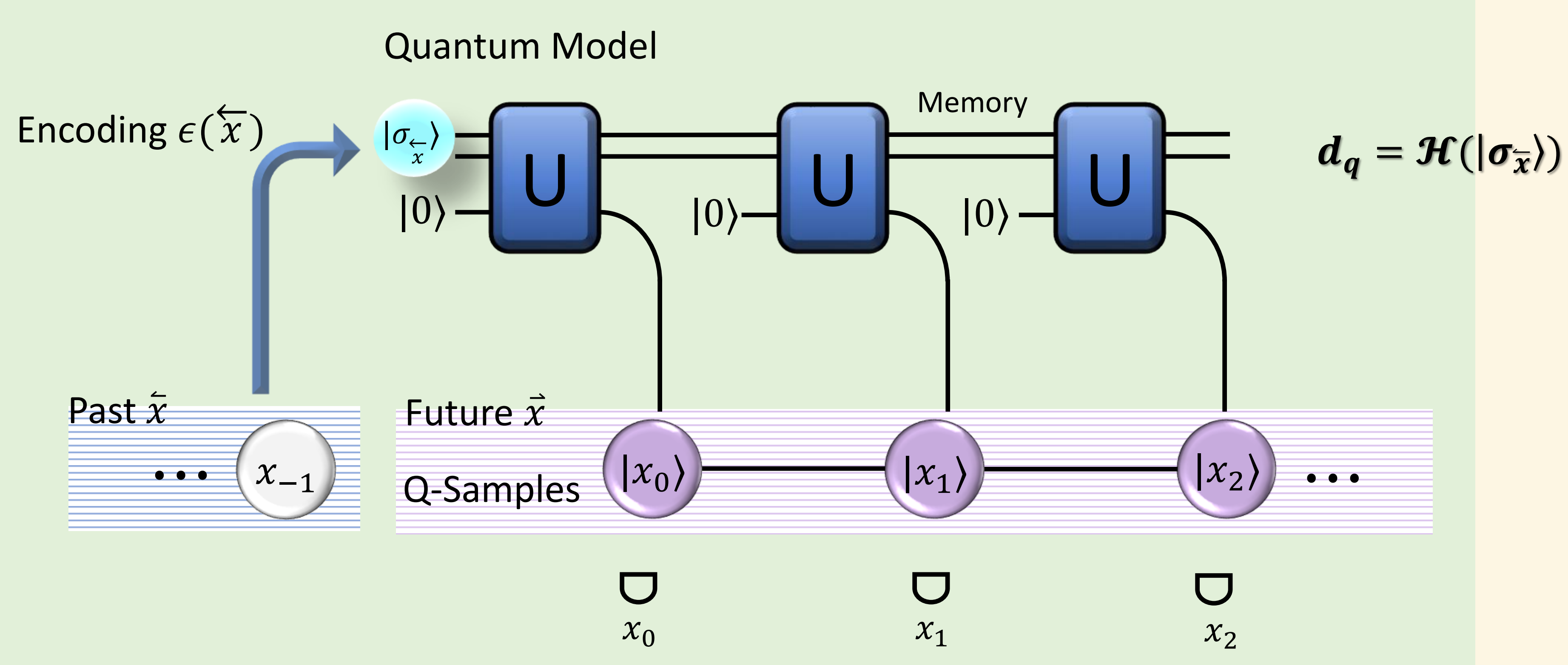
Memory cost and distortion



Predictive Models



Quantum models

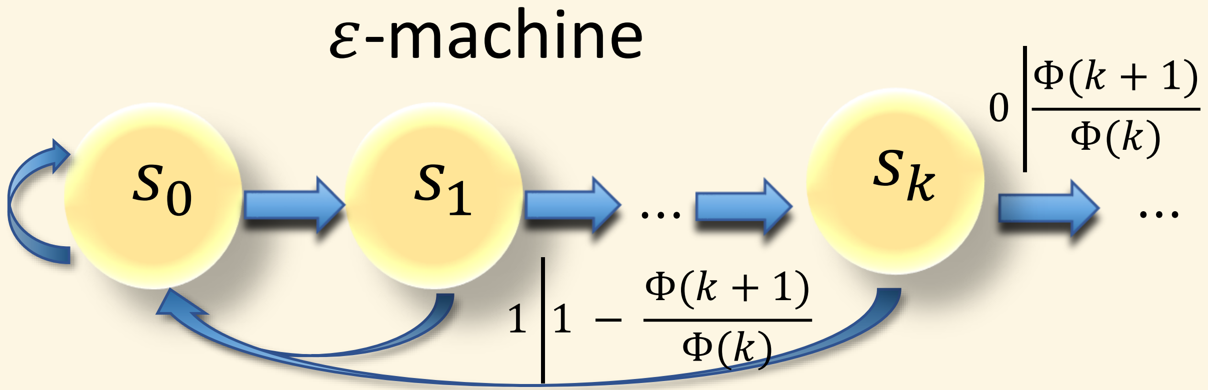


Binder, F. C., Thompson, J., & Gu, M. (2018). Practical unitary simulator for non-markovian complex processes. Physical review letters, 120(24), 240502.

Dual Poisson processes

Encoding

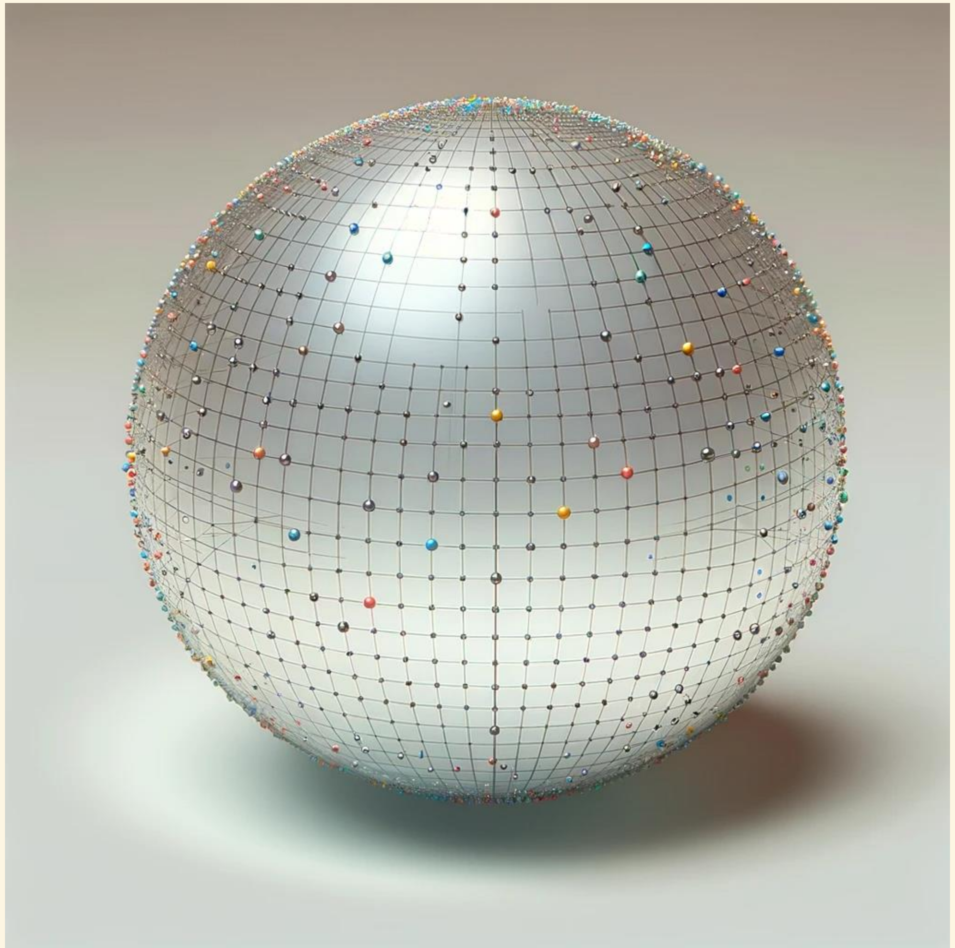
$$\cdots \underbrace{1000\cdots 0}_{k} \rightarrow s_k$$



$$\Phi(n) = p\Gamma_1^n + (1-p)\Gamma_2^n$$

Elliott, T. J., Yang, C., Binder, F. C., Garner, A. J., Thompson, J., & Gu, M. (2020). Extreme dimensionality reduction with quantum modeling. Physica Review Letters, 125(26), 260501.

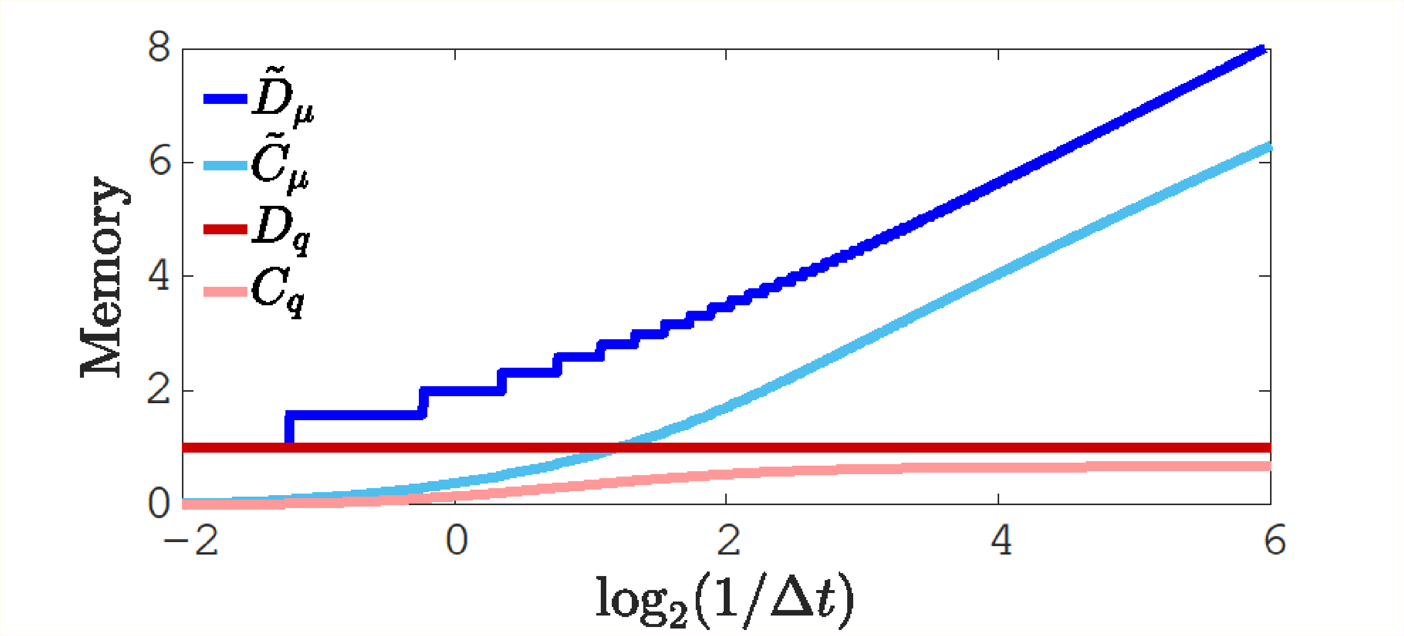
Single Qubit Model



Unitary operator

$$U|\sigma_k\rangle = \sqrt{\frac{\Phi(k+1)}{\Phi(k)}}|\sigma_{k+1}\rangle|0\rangle + \sqrt{1-\frac{\Phi(k+1)}{\Phi(k)}}|\sigma_0\rangle|1\rangle$$

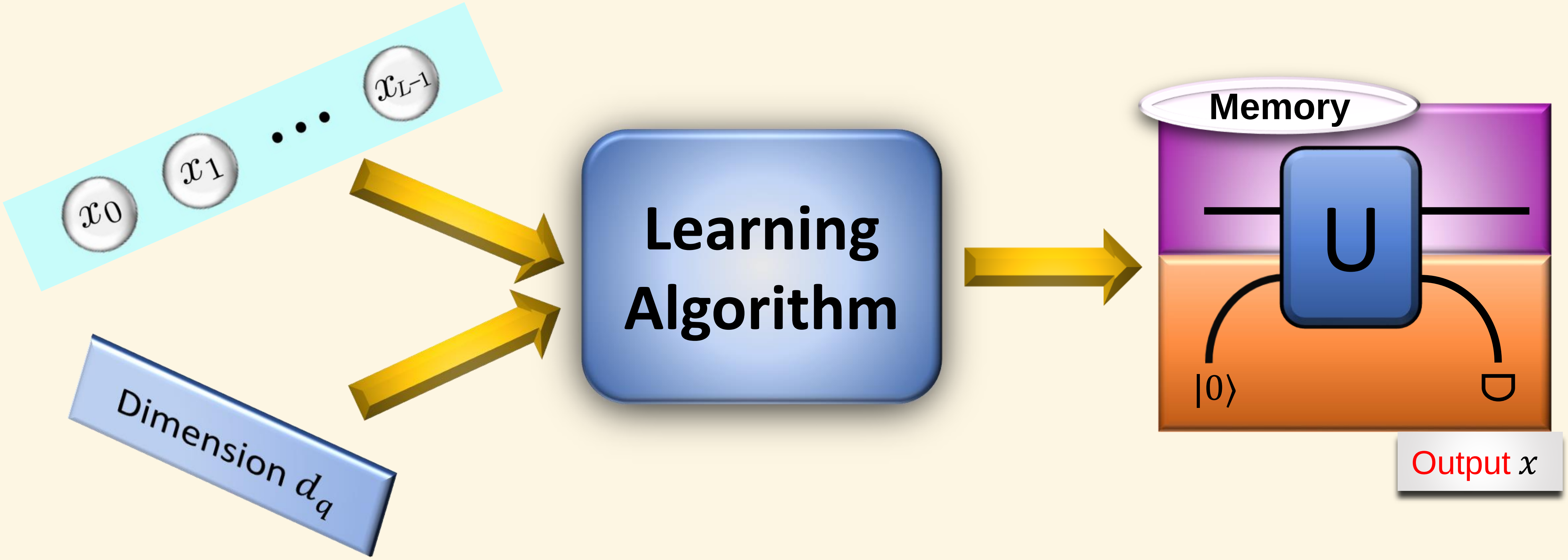
The amount of quantum memory



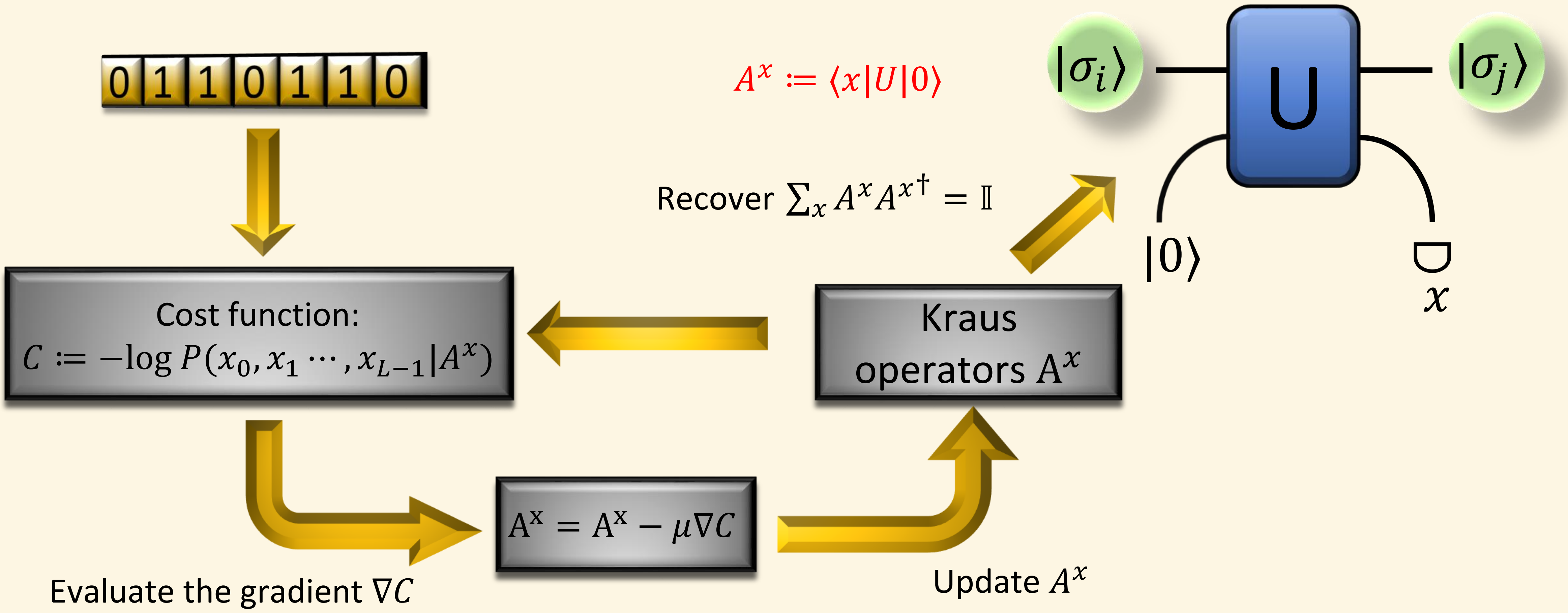
$\Gamma_i = \exp(-\gamma_i \Delta t)$

$\gamma_1 = 12, \gamma_2 = 1, p = 0.9$

Learn a model from data

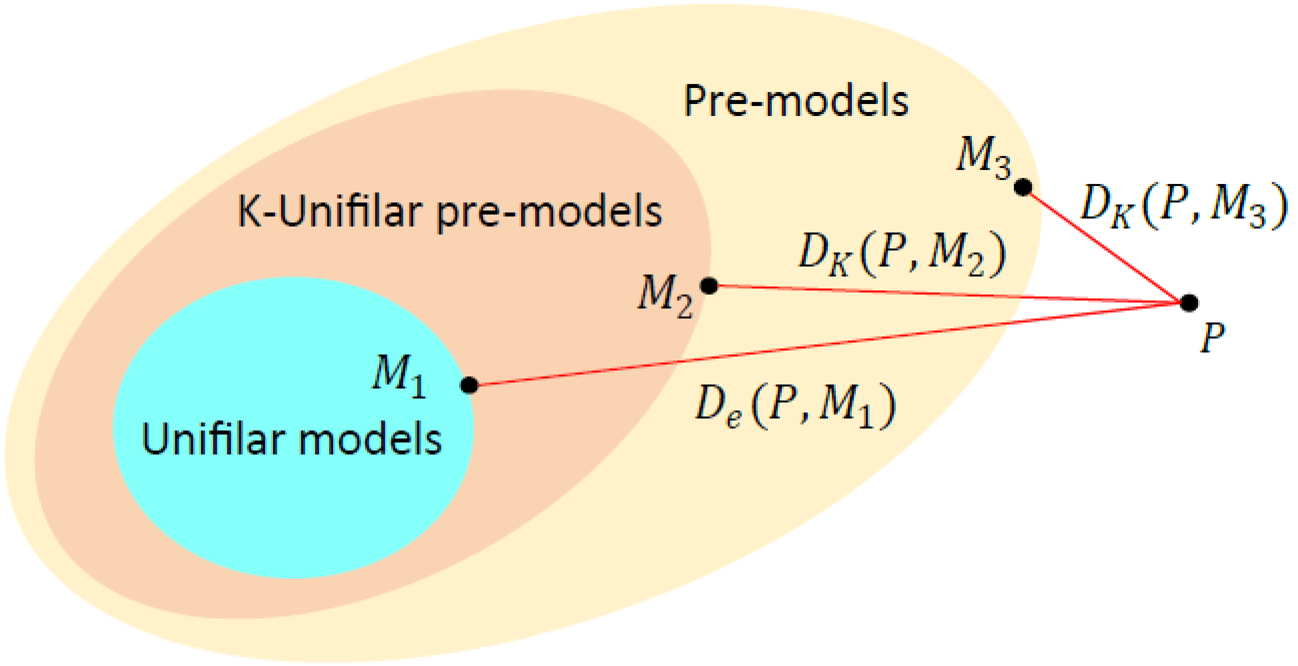


Learning Quantum Model



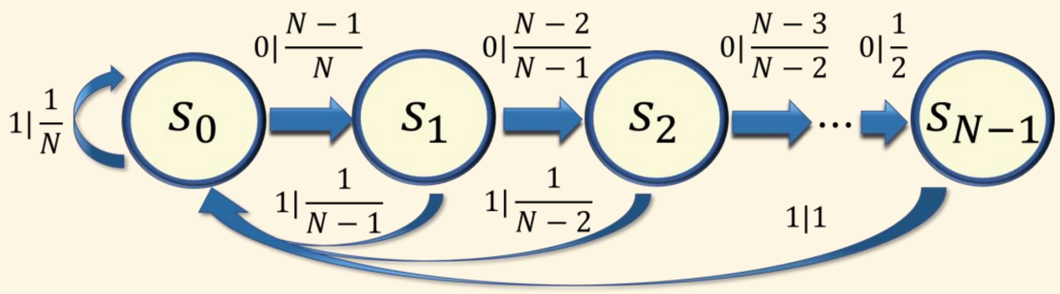
Yang, C., Garner, A. J., Liu, F., Tischler, N., Thompson, J., Yung, M. H., ... & Dahlsten, O. (2023). Provably superior accuracy in quantum stochastic modeling. Physical Review A, 108(2), 022411.

Classical Distortion Bound

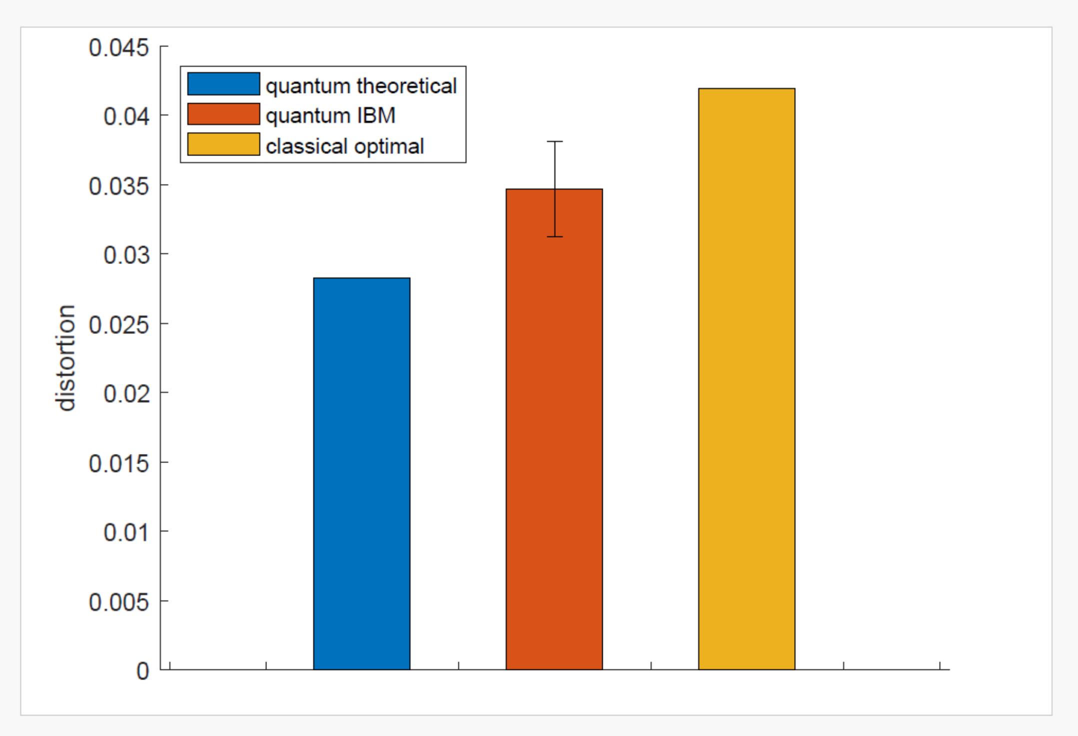


$$\min_{M \in \mathcal{M}_1^d} D_e(P, M) \geq \min_{M \in \mathcal{M}_K^d} D_e(P, M) = \min_{M \in \mathcal{M}_K^d} D_K(P, M) \geq \min_{M \in \mathcal{M}_\infty^d} D_K(P, M)$$

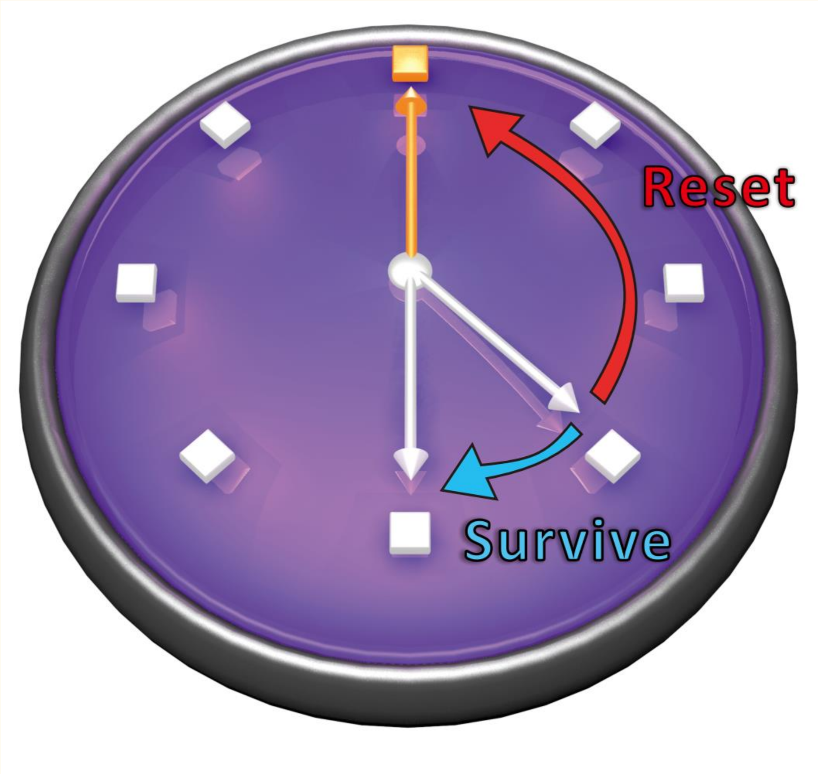
Training result and IBM Implementation



$d_C = d_q = 2, N = 3$



A Clock process

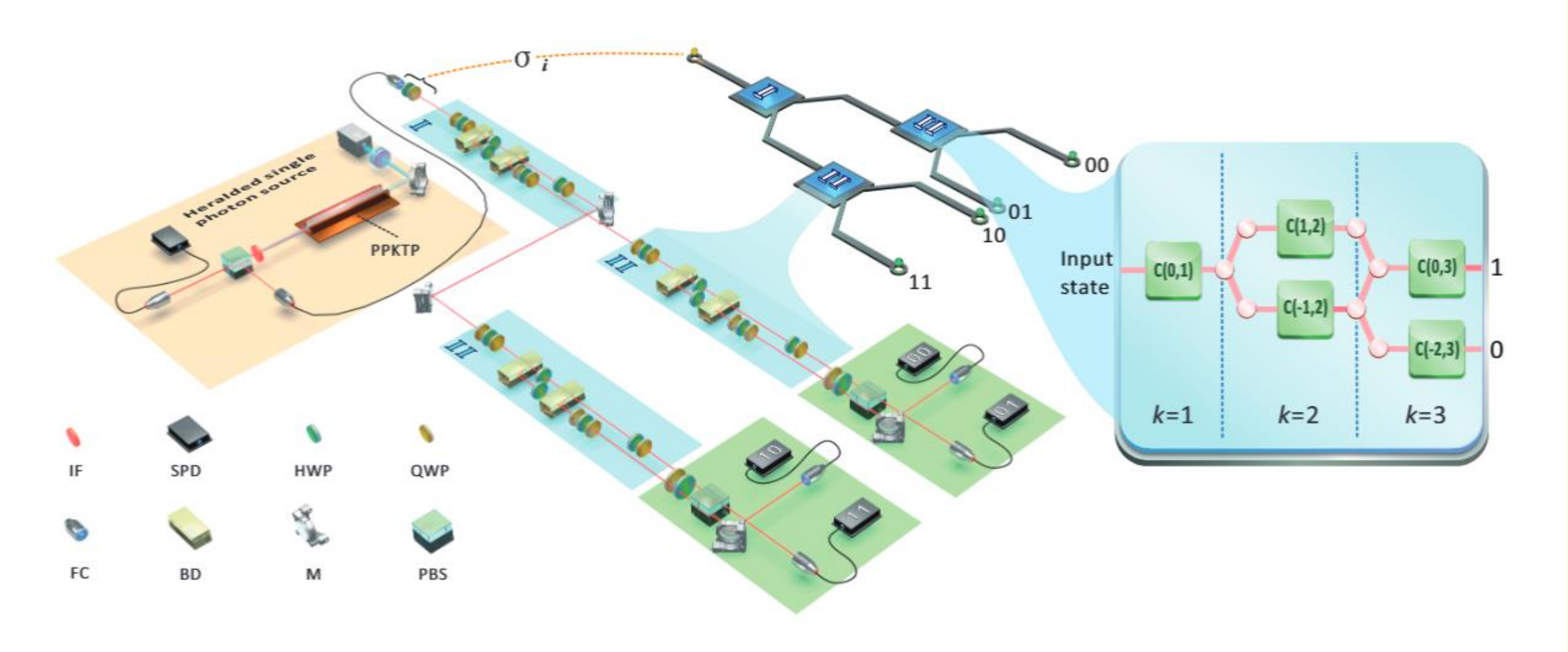


$$\Phi(n) = \Gamma^n(1 - V \sin^2 n\theta)$$

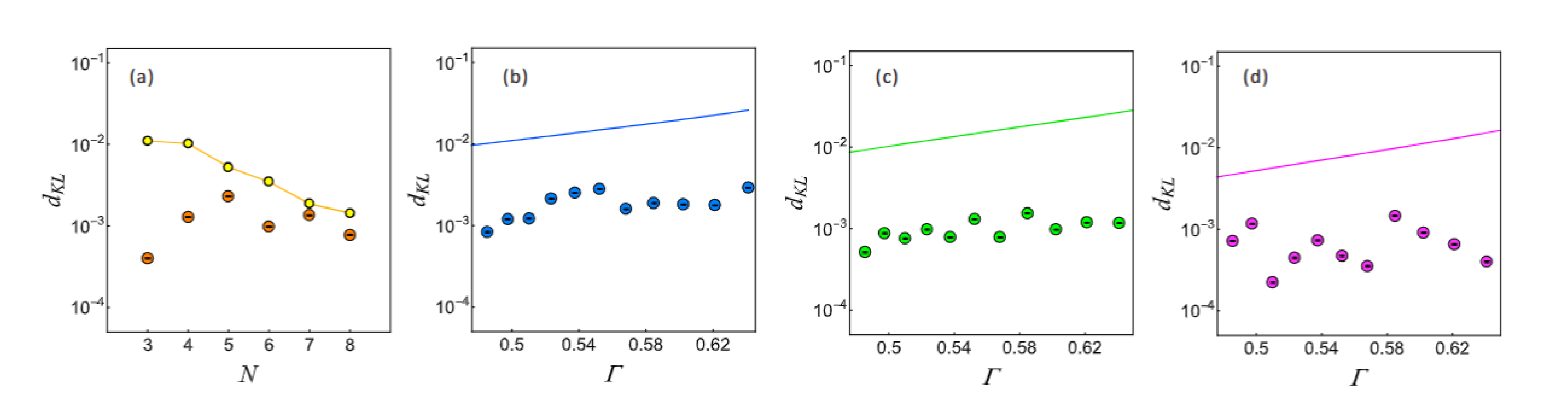
$$A_0|\sigma_n\rangle \propto |\sigma_{n+1\ mod\ N}\rangle$$
$$A_1|\sigma_n\rangle \propto |\sigma_0\rangle$$

Wu, K. D., Yang, C., He, R. D., Gu, M., Xiang, G. Y., Li, C. F., ... & Elliott, T. J. (2023). Implementing quantum dimensionality reduction for non-Markovian stochastic simulation. Nature Communications, 14(1), 2624.

Experimental Details



Experimental Results



Conclusion

1. There exists quantum models that present unbounded memory advantages over classical models
2. We develop a discovery algorithm to find accurate quantum models with reduced dimension
3. We experimentally implement quantum models that outperform the best classical model in terms of memory.