Hybrid Quantum Reservoir Computing

for simulating chaotic systems

presented by: Filip Wudarski

on ArXiv on Monday
Available at:
https://github.com/filutek/HQRC_paper/blob/main/main.pdf

FW, Daniel O'Connor, Shaun Geaney, Ata Akbari Asanjan, Max Wilson, Elena Strbac, Aaron Lott, Davide Venturelli

Agenda

- Classical reservoir computing
- Hybrid Quantum Reservoir Computing (HQRC)
- Lorenz63 - a chaotic system
- Results
  - Simulations
  - QPU
- Conclusions

Classical reservoir computing

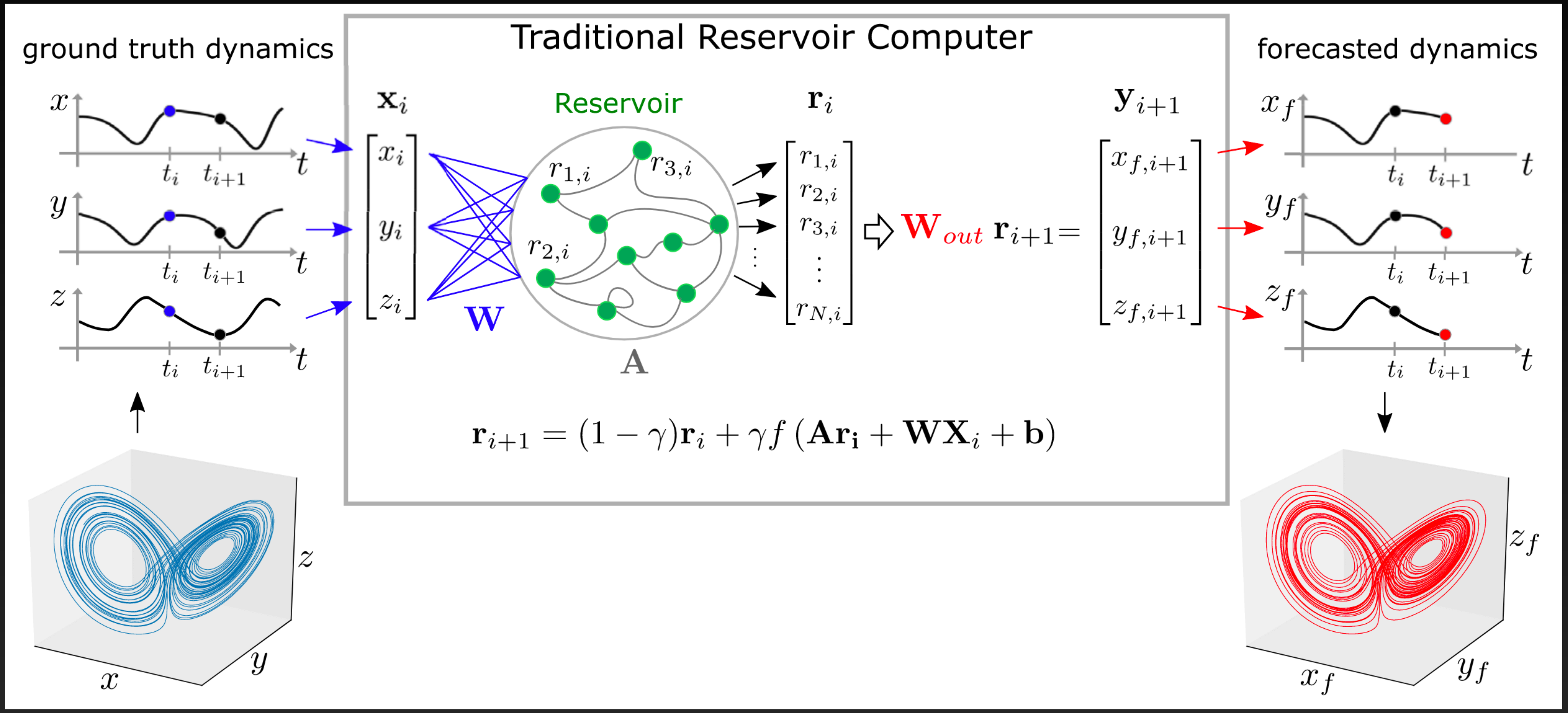
Randomized recurrent neural network

W } Random matrices
A

b Random vector

r_t Reservoir state

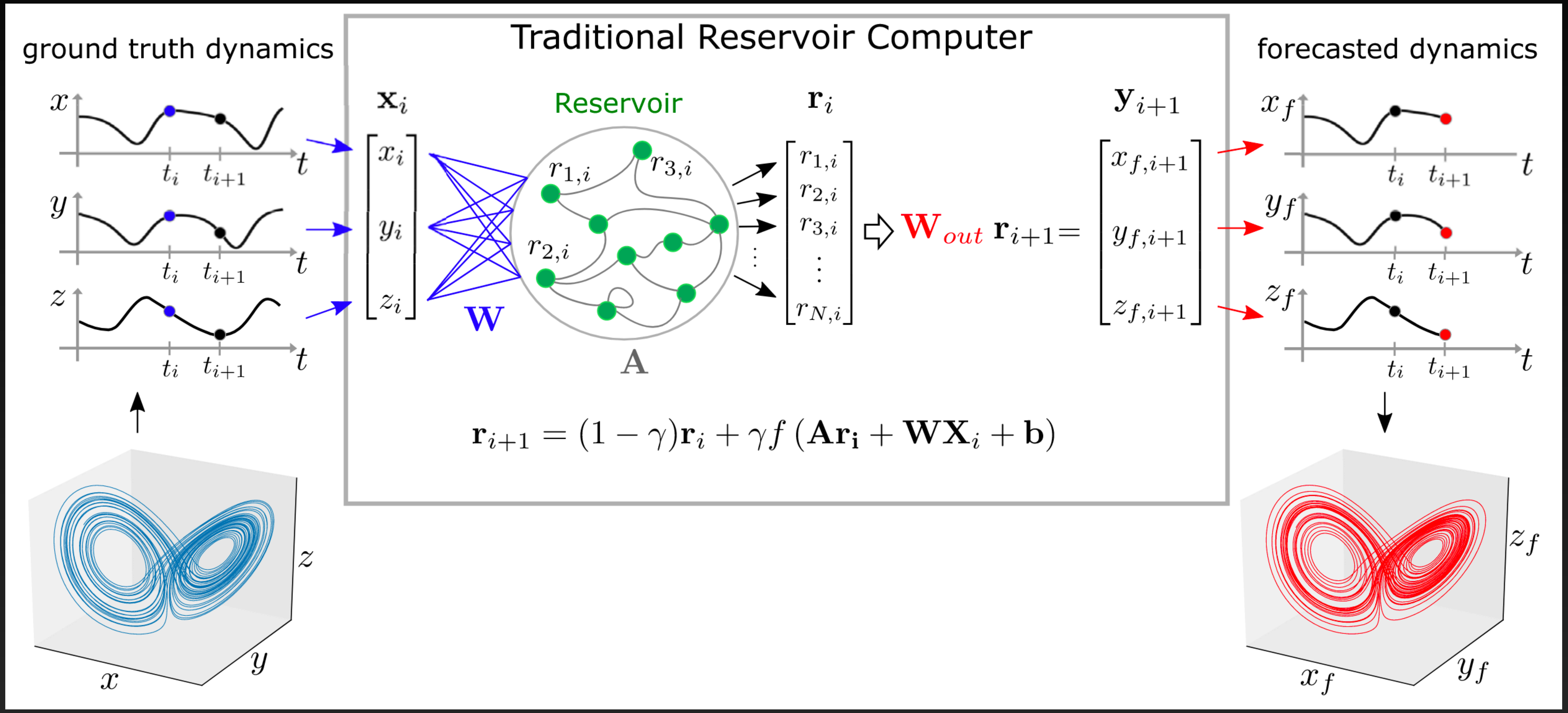
W_{out} Trainable weights



RC paradigm is particularly useful for learning dynamical systems (time series), even when the dynamics is chaotic. RC is a viable tool for weather modeling or broad ESG applications.

D. J. Gauthier et. al, Nat. Comm. 12: 5564 (2021)

Hybrid Quantum Reservoir Computing



How to exploit the most power of quantum mechanics?

How to extend that framework for weather modeling?

Prior work on QRC

*K. Fuji, and K. Nakajima, Phys. Rev. Applied **8**, 024030 (2017)*
*P. Mujal et. al, Advanced Quantum Technologies, **8**, 2100027 (2021)*
*R. A. Bravo, et. al, PRX Quantum **3**, 030325 (2022)*
P. Pfeffer, F. Heyder, and J. Schumacher, arXiv: 2204.13951 (2022), 2307.03053 (2023)
P. Mujal et. al, npj Quantum Inf. 9, 16 (2023)
A. Sornsaeng, N. Dangniam, T. Chotibut, arXiv: 2308.14239 (2023) (Next talk)

and more

D. J. Gauthier et. al, Nat. Comm. 12: 5564 (2021)

Hybrid Quantum Reservoir Computing

$A \longrightarrow$ Quantum circuit U_R

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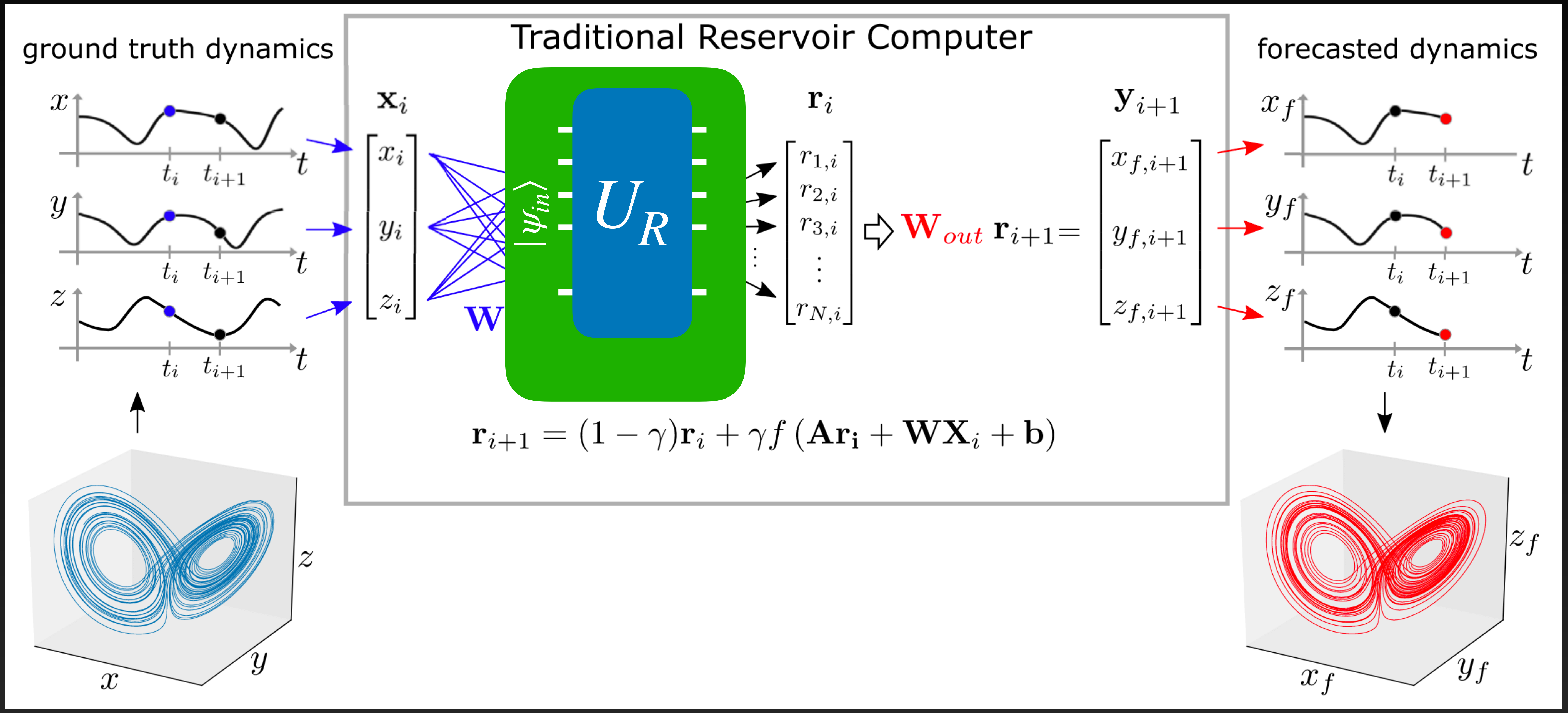

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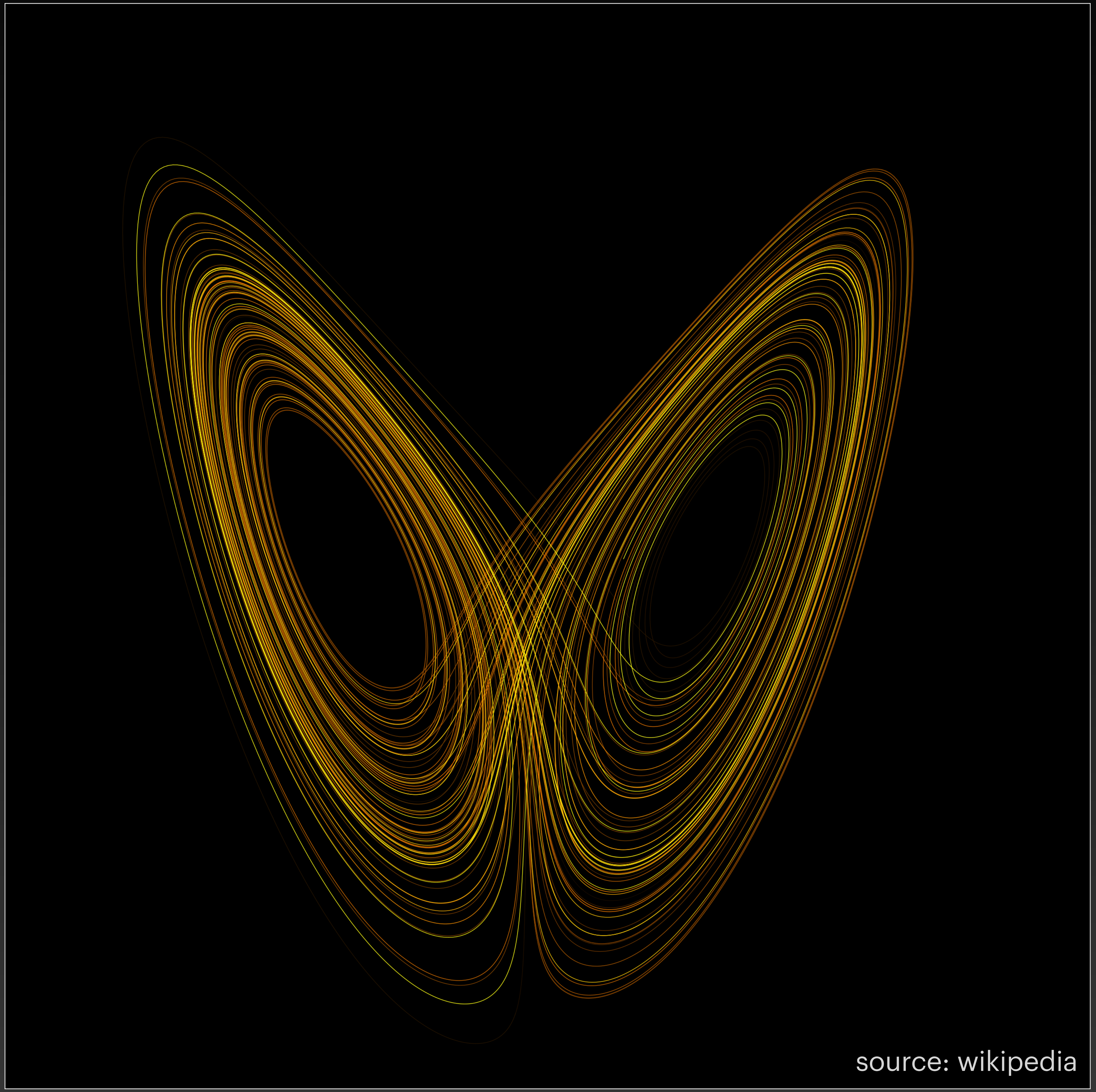
Hybrid Quantum Reservoir Computing

Lorenz63 - a chaotic system

Lorenz63 a simplified model for atmospheric convection, governed by a system of ODEs:

$$\dot{x} = 10(y - x)$$
$$\dot{y} = x(28 - z) - y$$
$$\dot{z} = xy - 8z/3$$



Lorenz attractor

Results
Classical simulations

Valid prediction time (VPT)

$$RMSE(t) = \sqrt{\frac{1}{D}\sum_{i=1}^{D}\left(\frac{\tilde{y}_i(t) - y_i(t)}{\sigma_i}\right)^2} \geq \varepsilon$$

8 qubits:

Layers: R3 | CX | R3 | CX

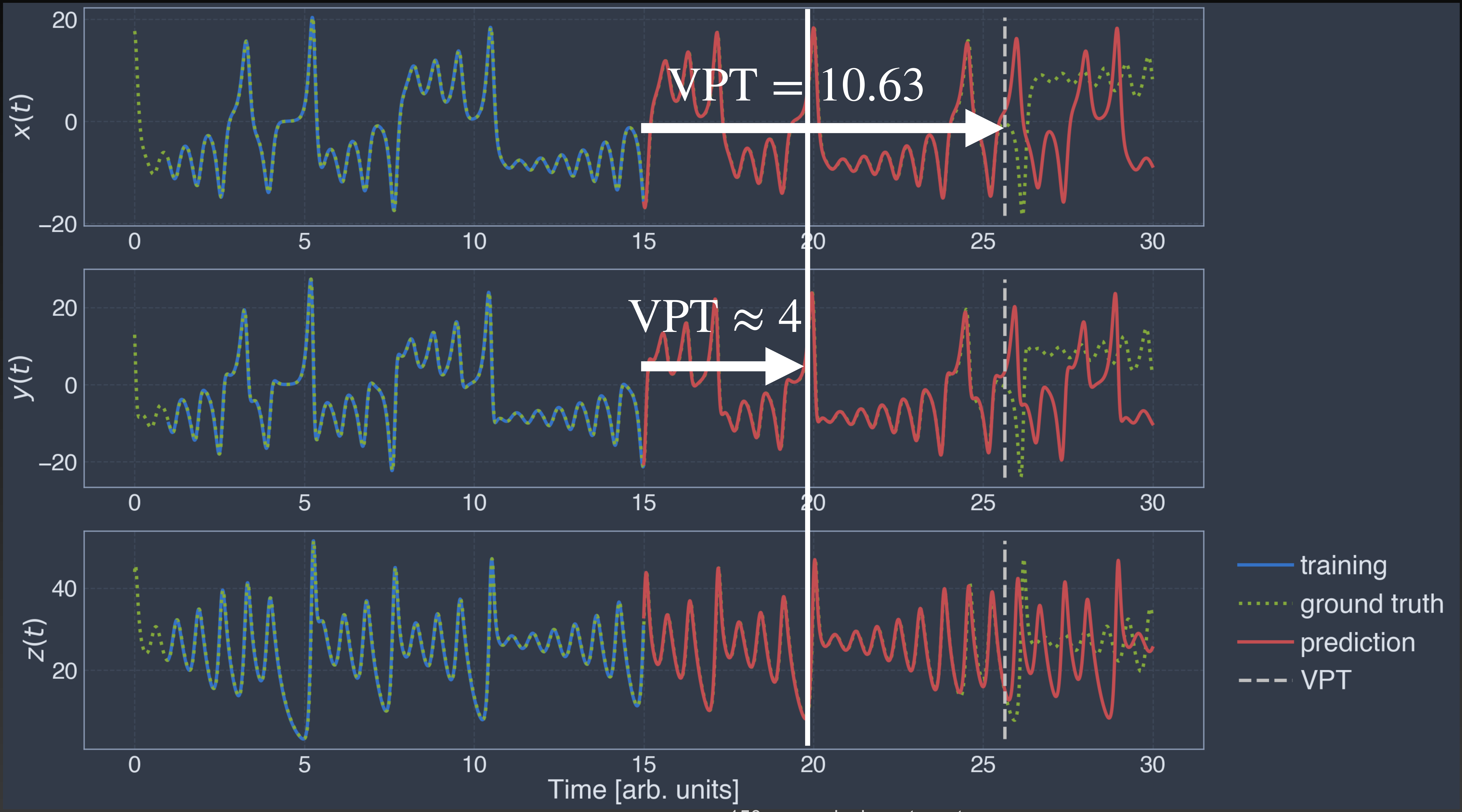
Measurements: single and two-qubit correlators

Reservoir size: 108

VPT = 10.63

Results

Classical simulations



150 reservoir size + two-step optimization

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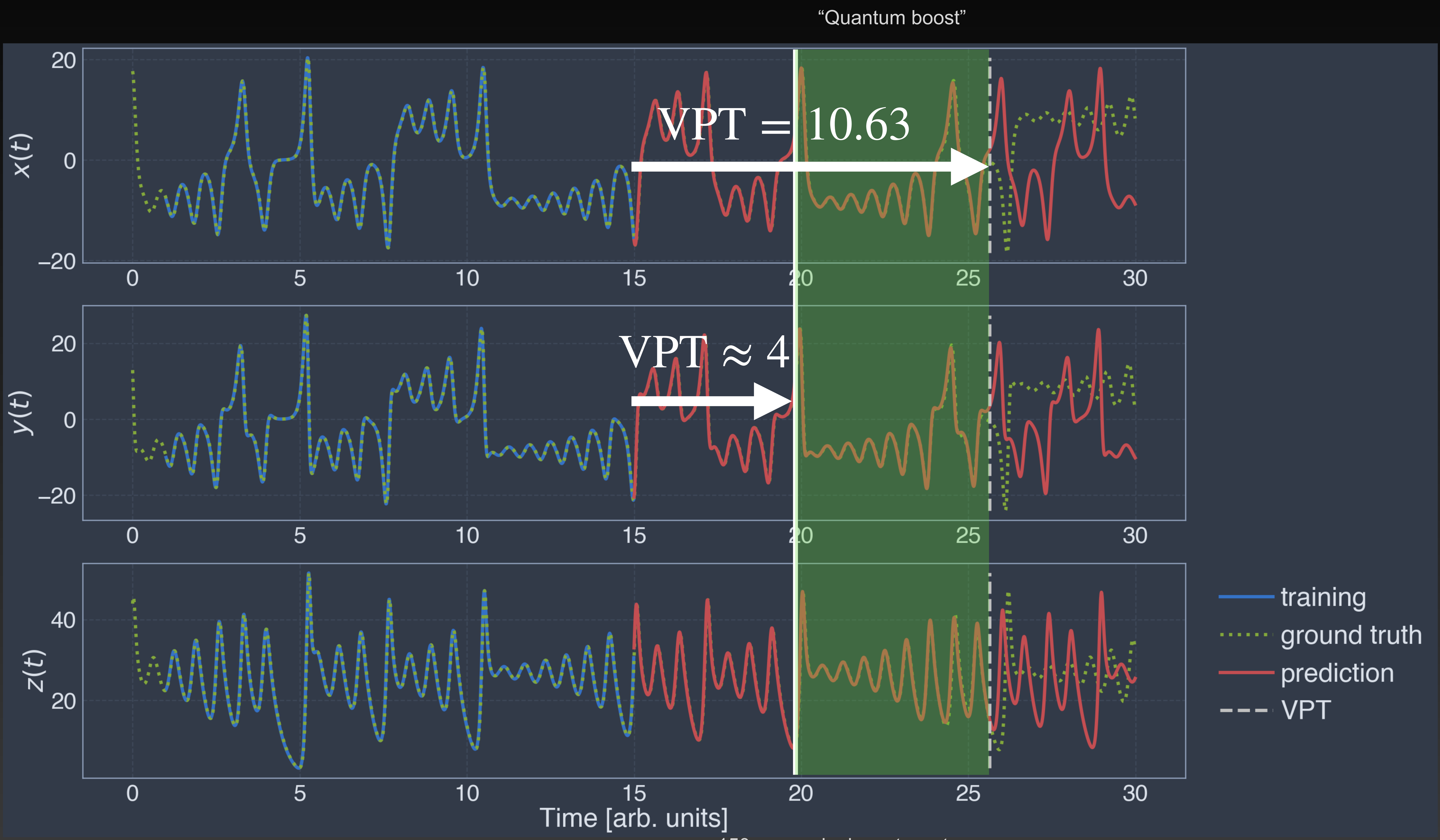

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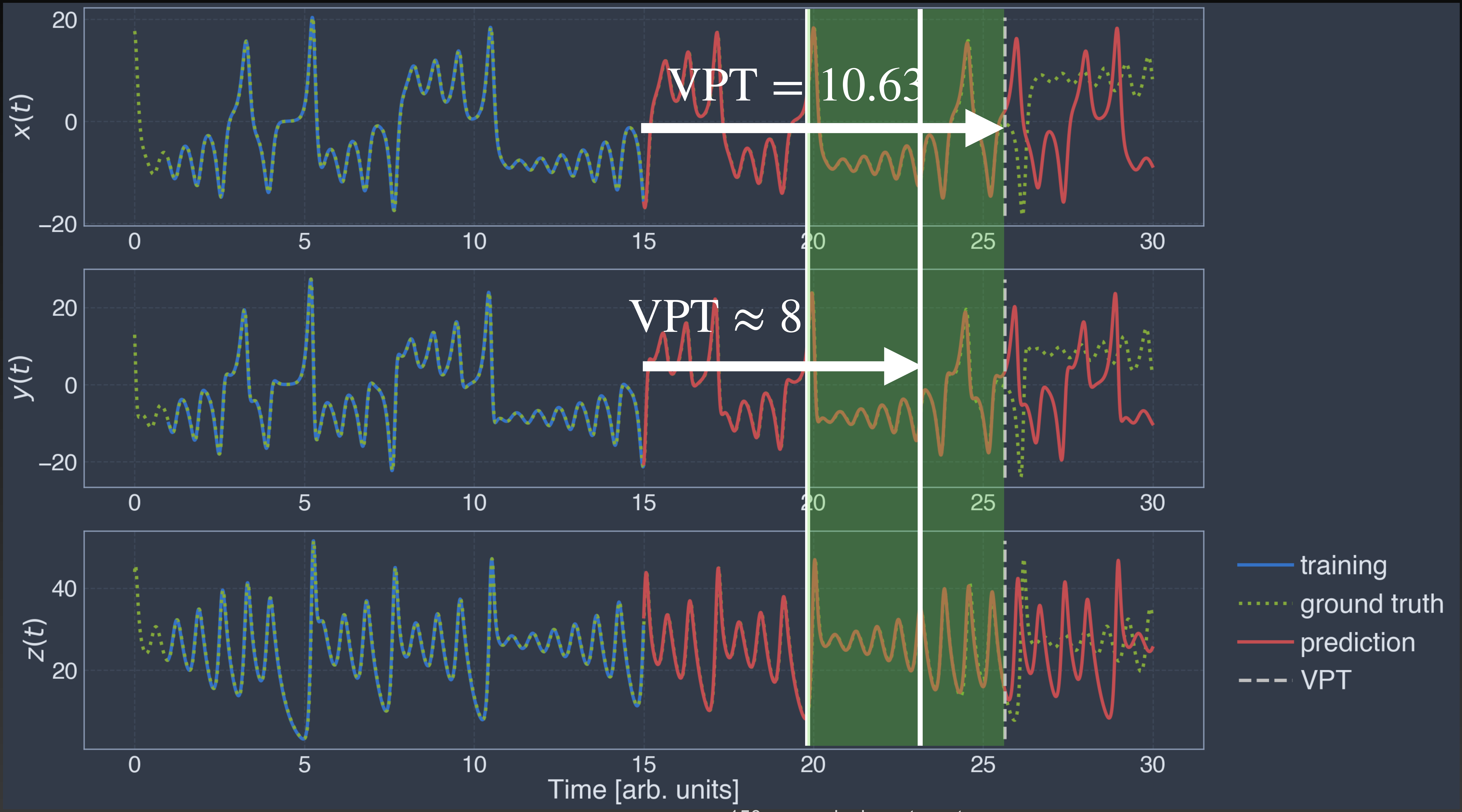
Classical simulations

"Quantum boost"



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Valid prediction time (VPT)

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Classical simulations

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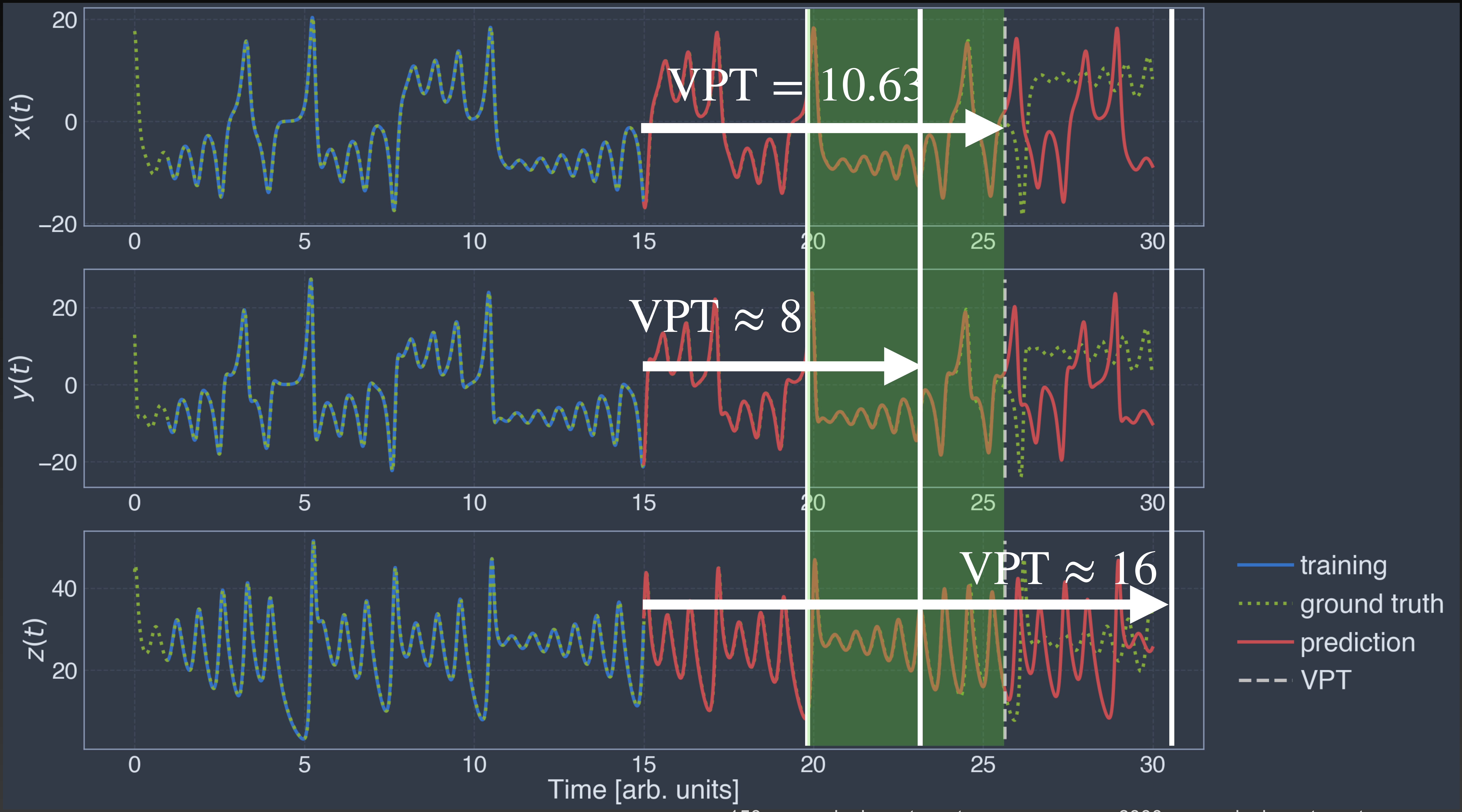


150 reservoir size + two-step optimization

6000 reservoir size + two-step optimization

Valid prediction time (VPT)

$$RMSE(t) = \sqrt{\frac{1}{D}\sum_{i=1}^{D}\left(\frac{\tilde{y}_i(t) - y_i(t)}{\sigma_i}\right)^2} \geq \varepsilon$$

8 qubits:

Layers: R3 | CX | R3 | CX

Measurements: single and two-qubit correlators

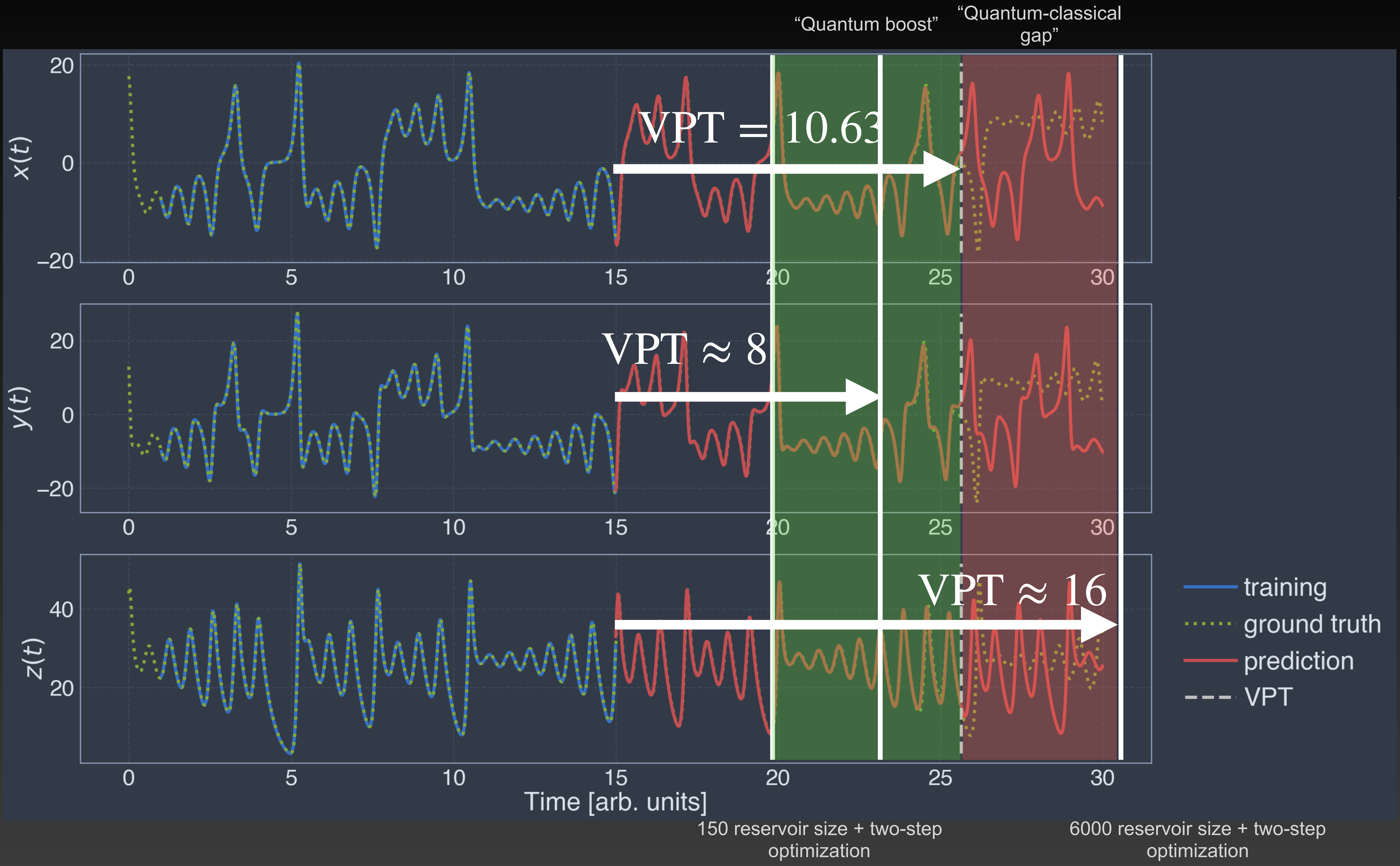
Reservoir size: 108

VPT = 10.63

Neural Net. **153**, 530-552, (2022)

Results

Classical simulations



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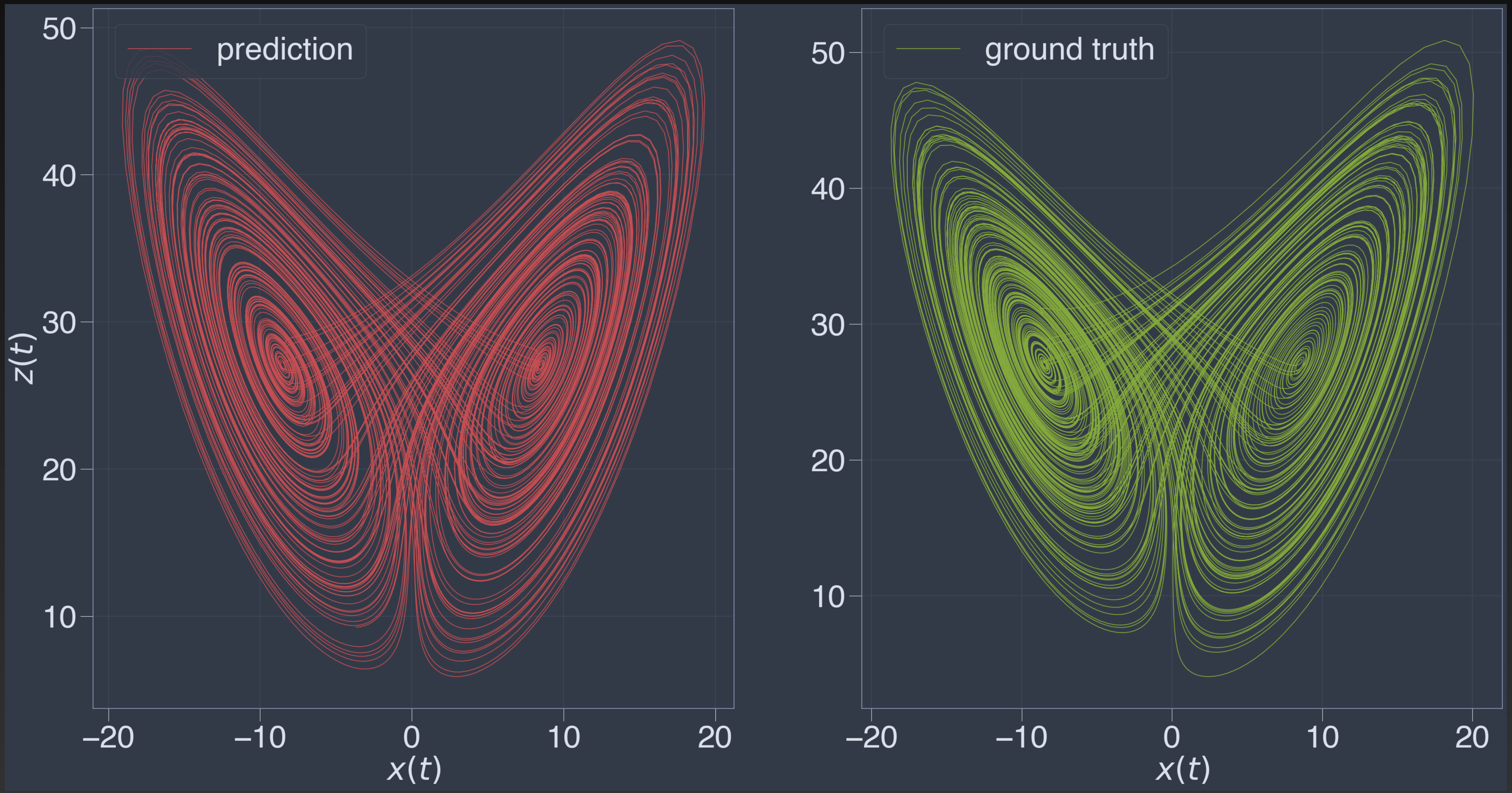
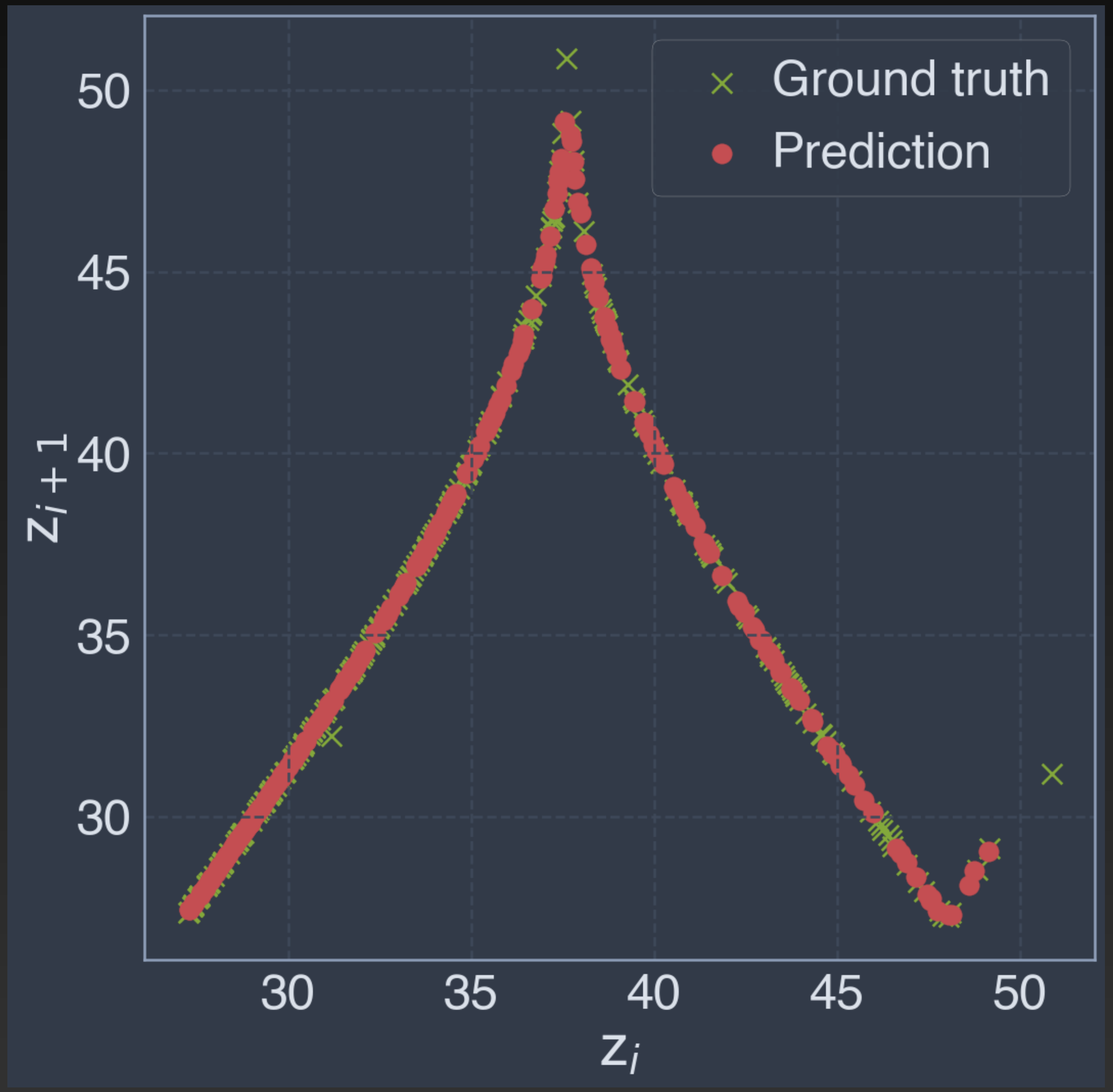


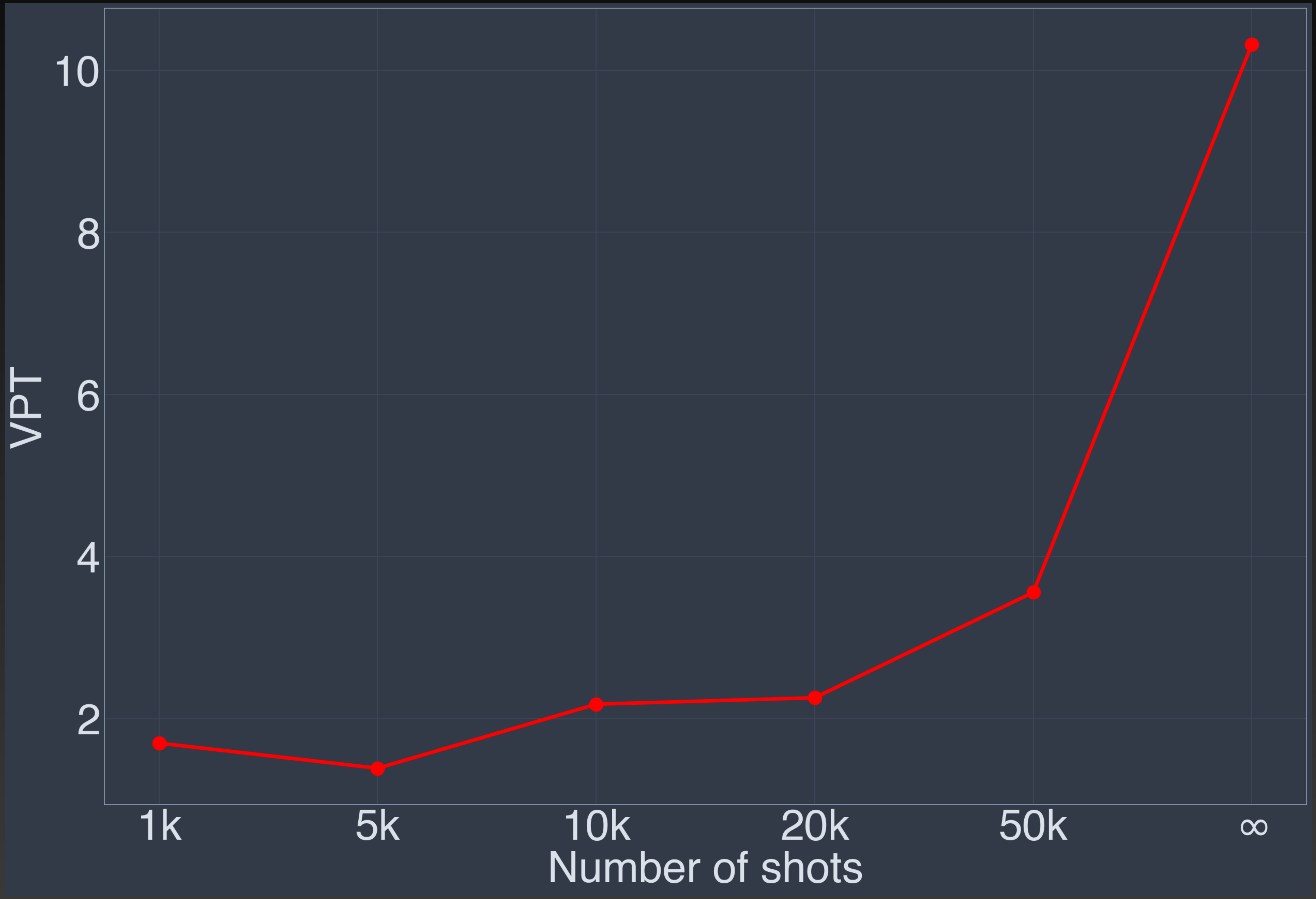
Attractor reconstruction



Poincaré return map

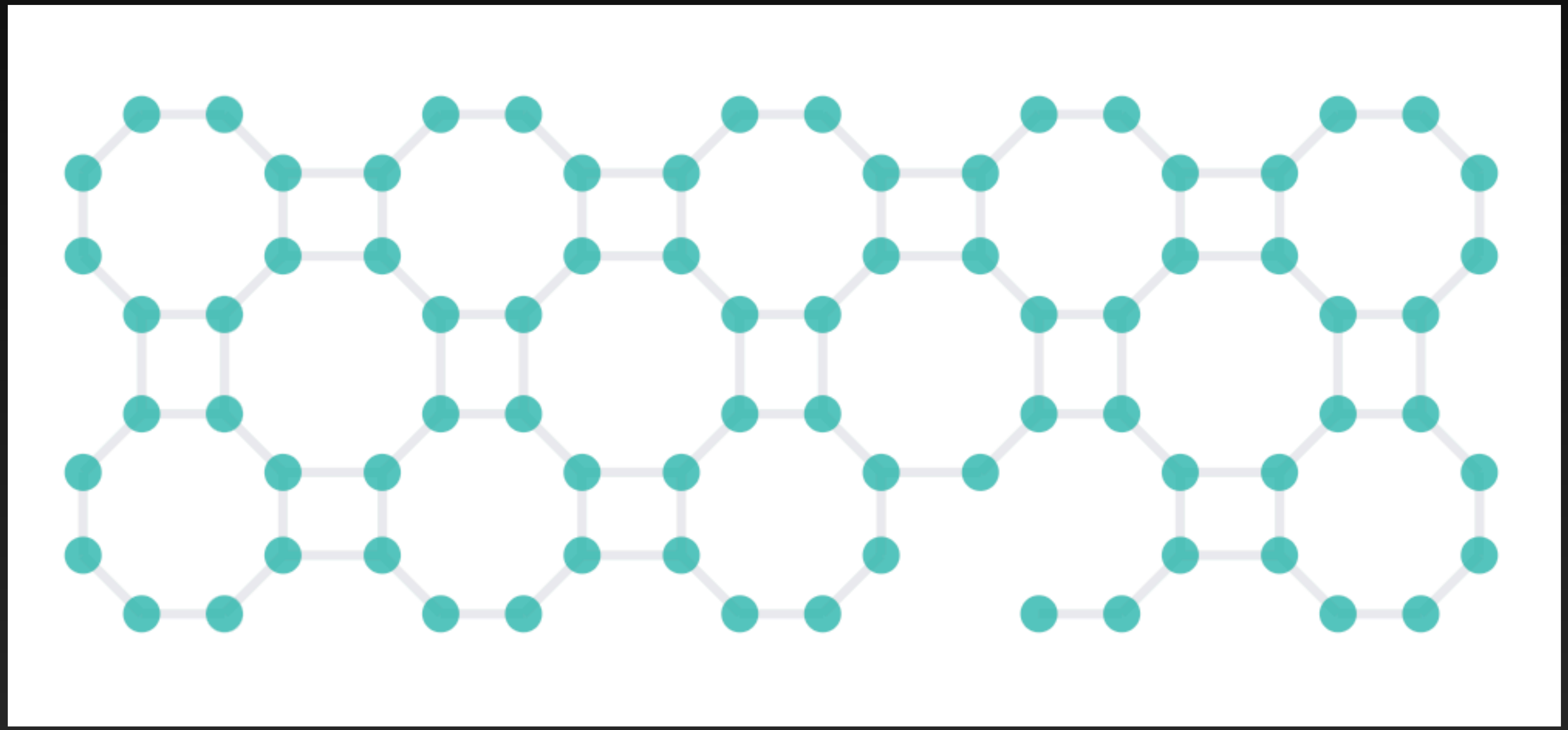
Results

Classical simulations

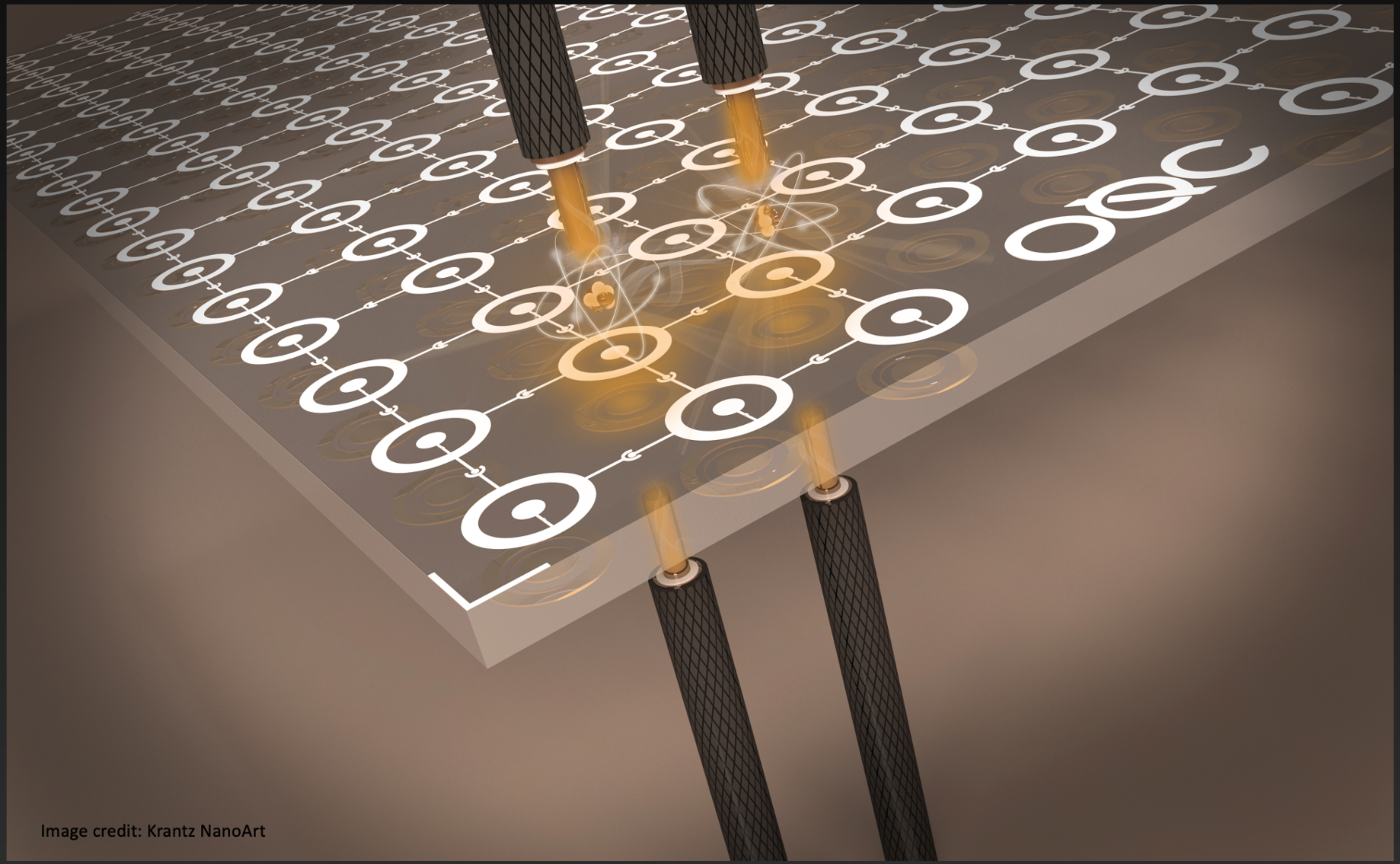


QPUs

Rigetti Aspen M-3 chip



OQC Lucy



Images: qcs.rigetti.com/lattices and oxfordquantumcircuits.com/gallery

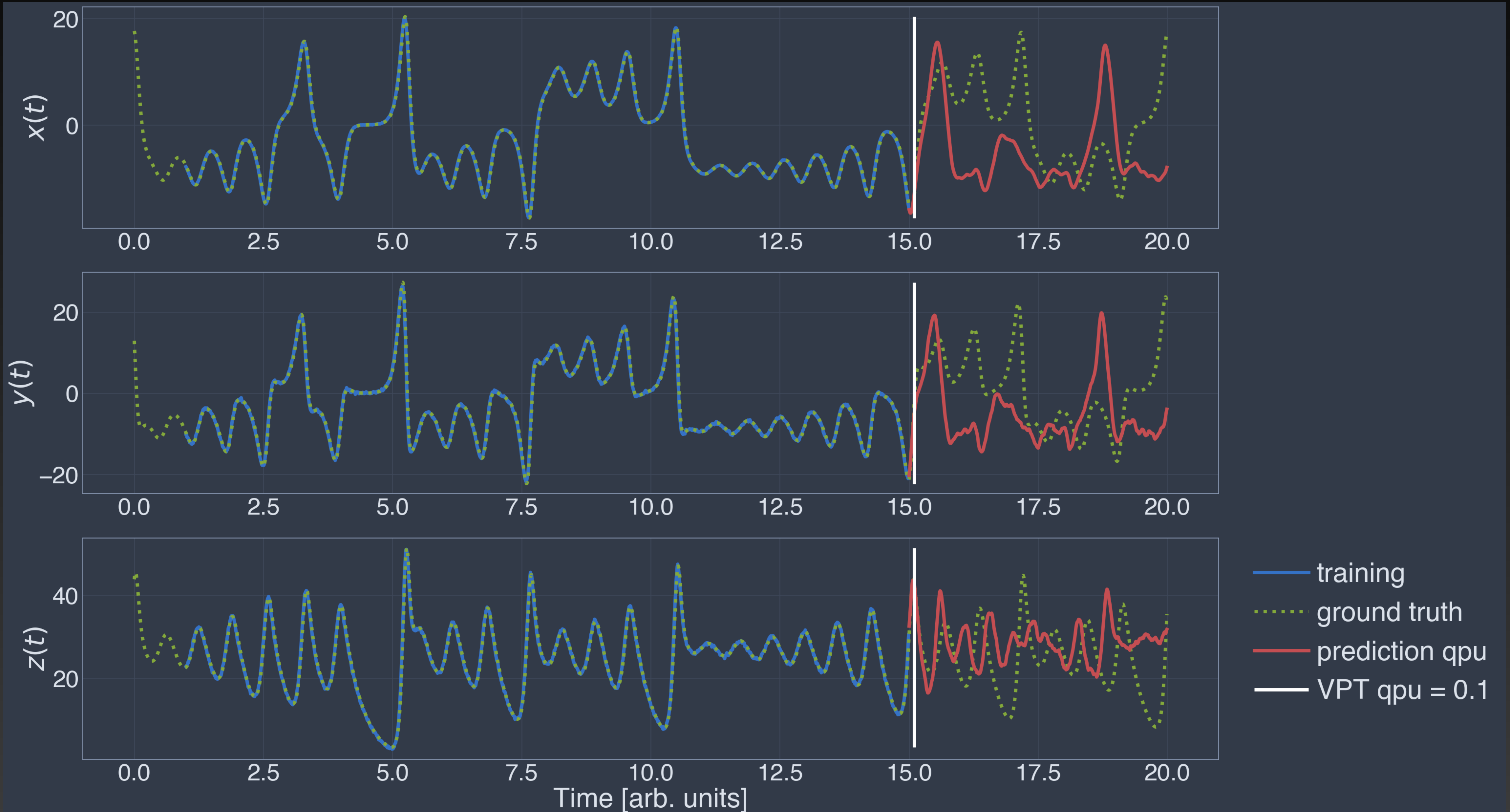
Results
QPU simulations

Lucy

8 qubits

2 CX layers

10k shots



Results

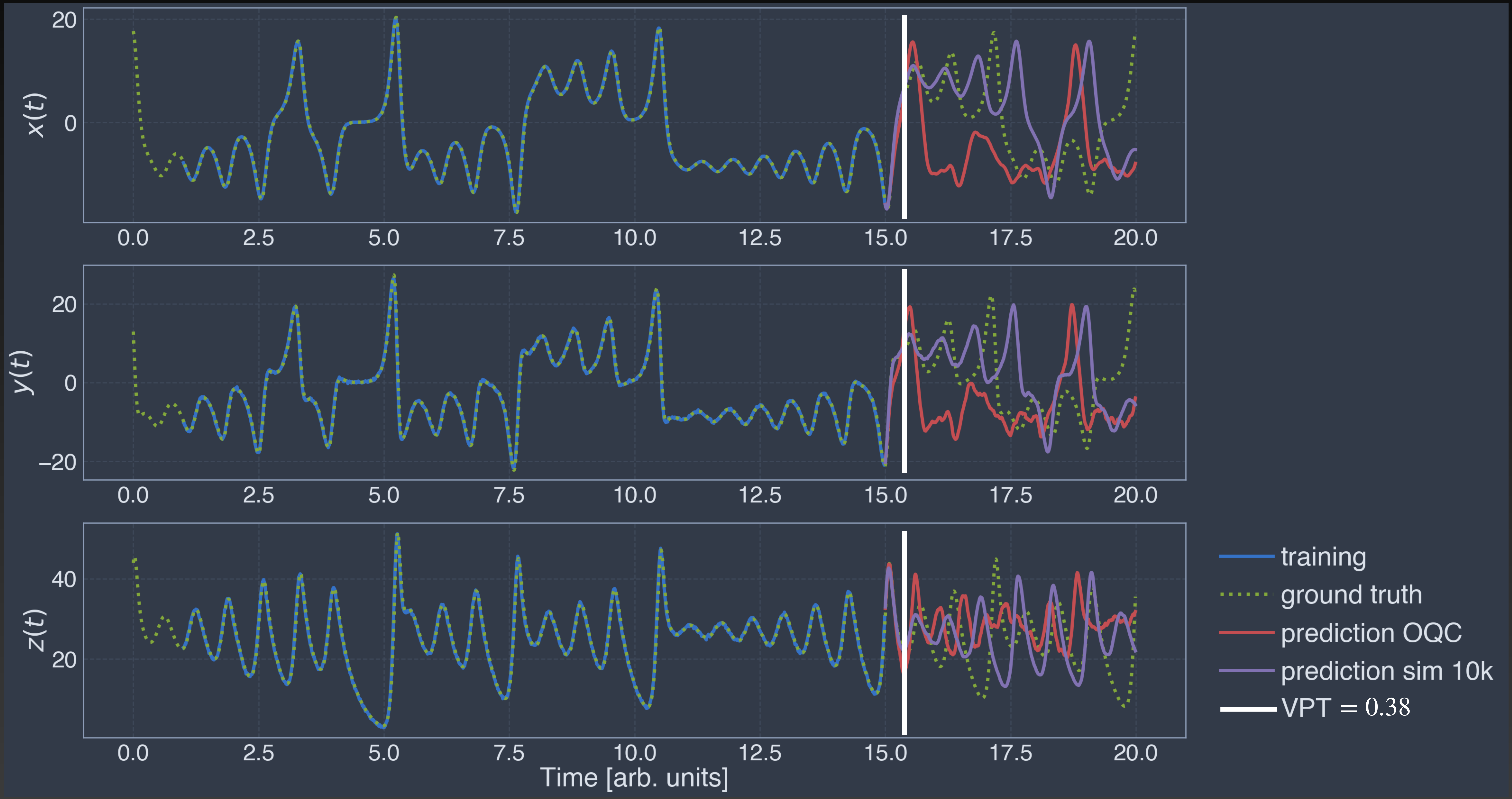
QPU simulations

Lucy

8 qubits

No CX layers

10k shots



Conclusions

- The HQRC is a computational framework providing accurate short- and long-term predictions for low-dimensional chaotic systems.
- The HQRC has potential to compete with classical RC (theoretically)
- Experimentally we need more stability in processors and/or devise error mitigation strategies tailored for The HQRC
- HQRC doesn’t involve optimization of circuits, so **NO** barren plateaus

SCAN ME

on ArXiv on Monday
Available at:
https://github.com/filutek/HQRC_paper/blob/main/main.pdf