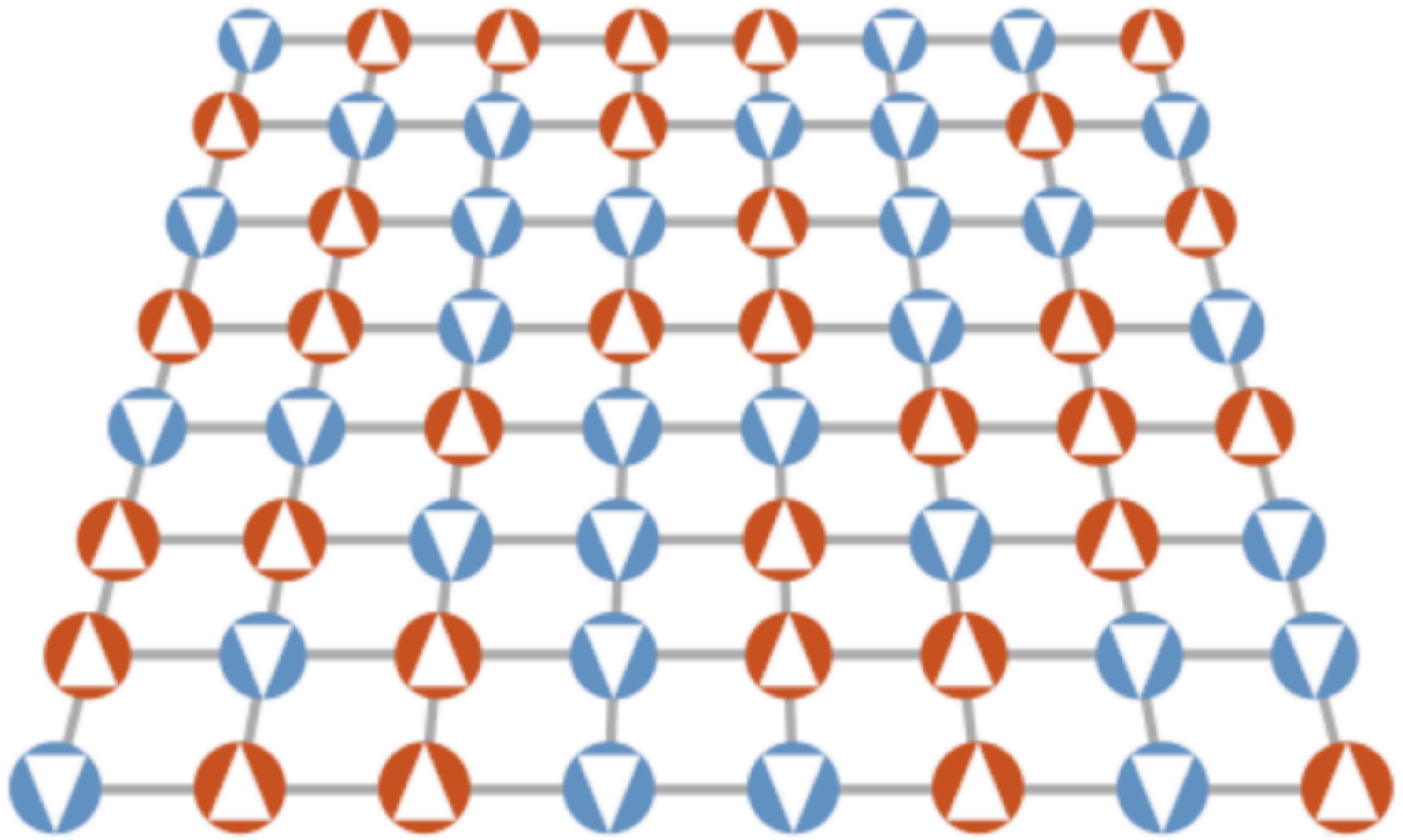
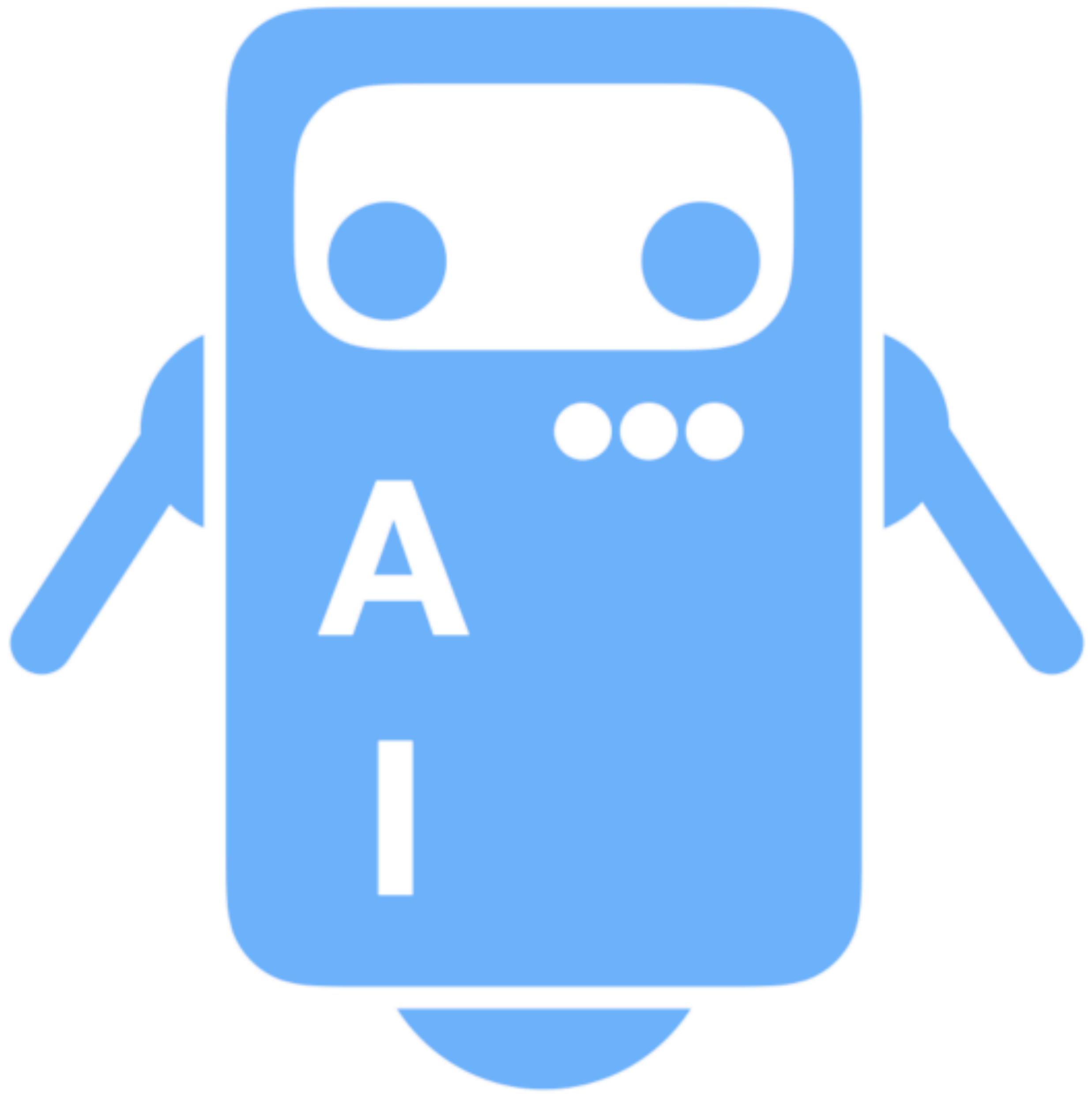
Machine Learning Quantum Matter

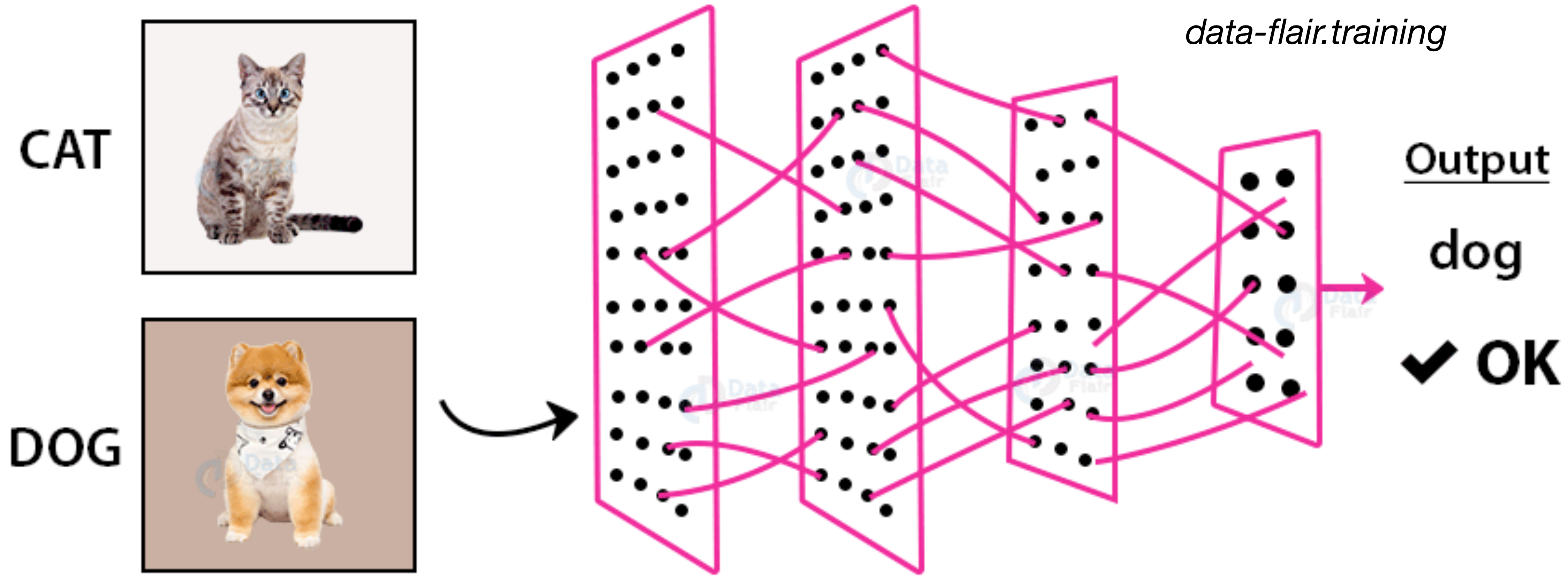


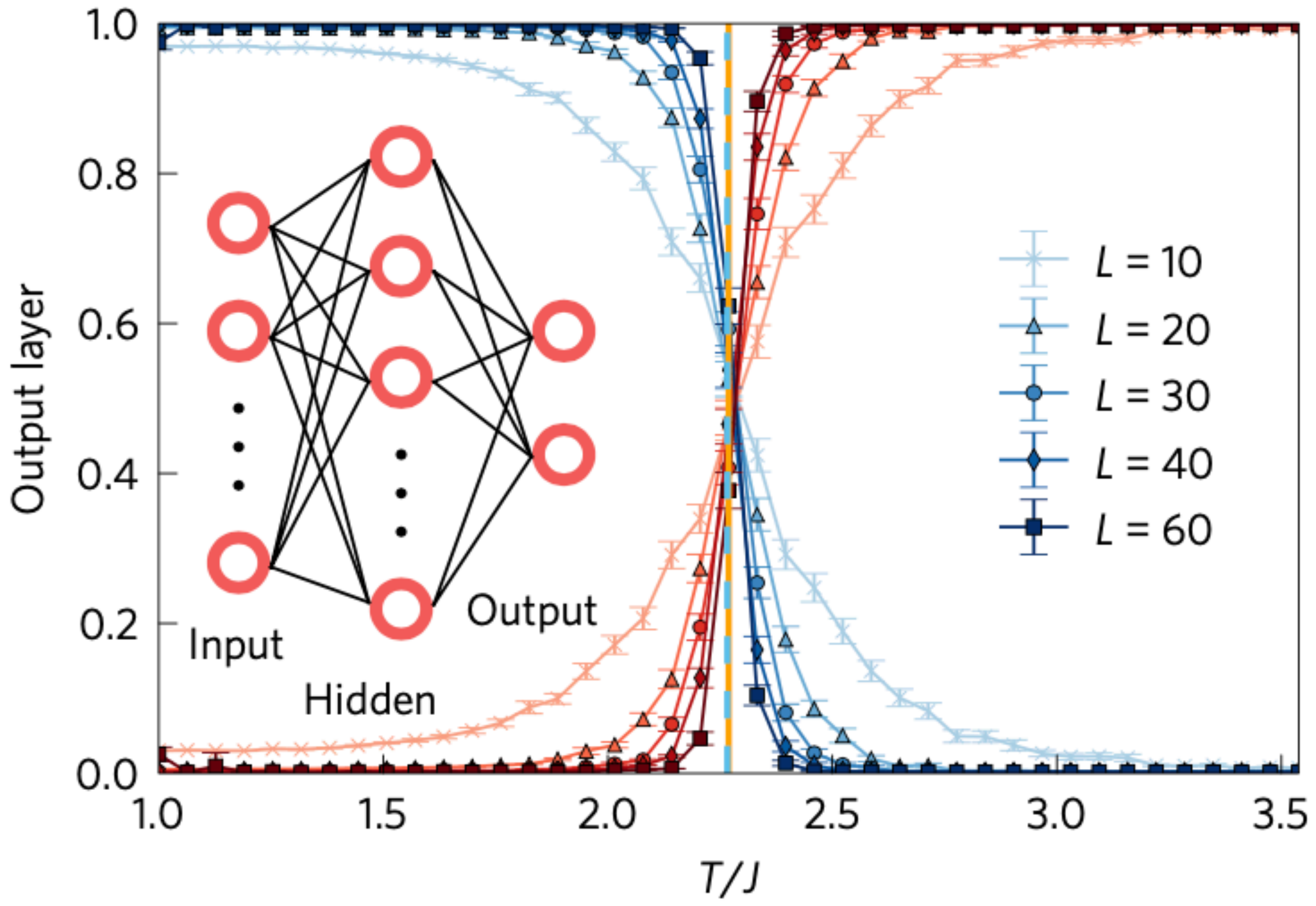


Info

- **<u>Time:</u>**
  - **Mondays - 3:30pm or 4pm?**
- **<u>Presentations:</u>**
  - **Content of 1-2 papers + general intro to relevant ML concepts**
  - **45-60 minutes + questions**
  - **Ideally: intro to ML technique (first half), physics application (second half)**
- **<u>Hands-on exercises (voluntary!):</u>**
  - **Let's try to machine-learn some simple stuff using Julia**
    (Reading hand-written digits, generating "hand-written" digits, Navigating a grid-world)

1 - Supervised learning of many-body phases

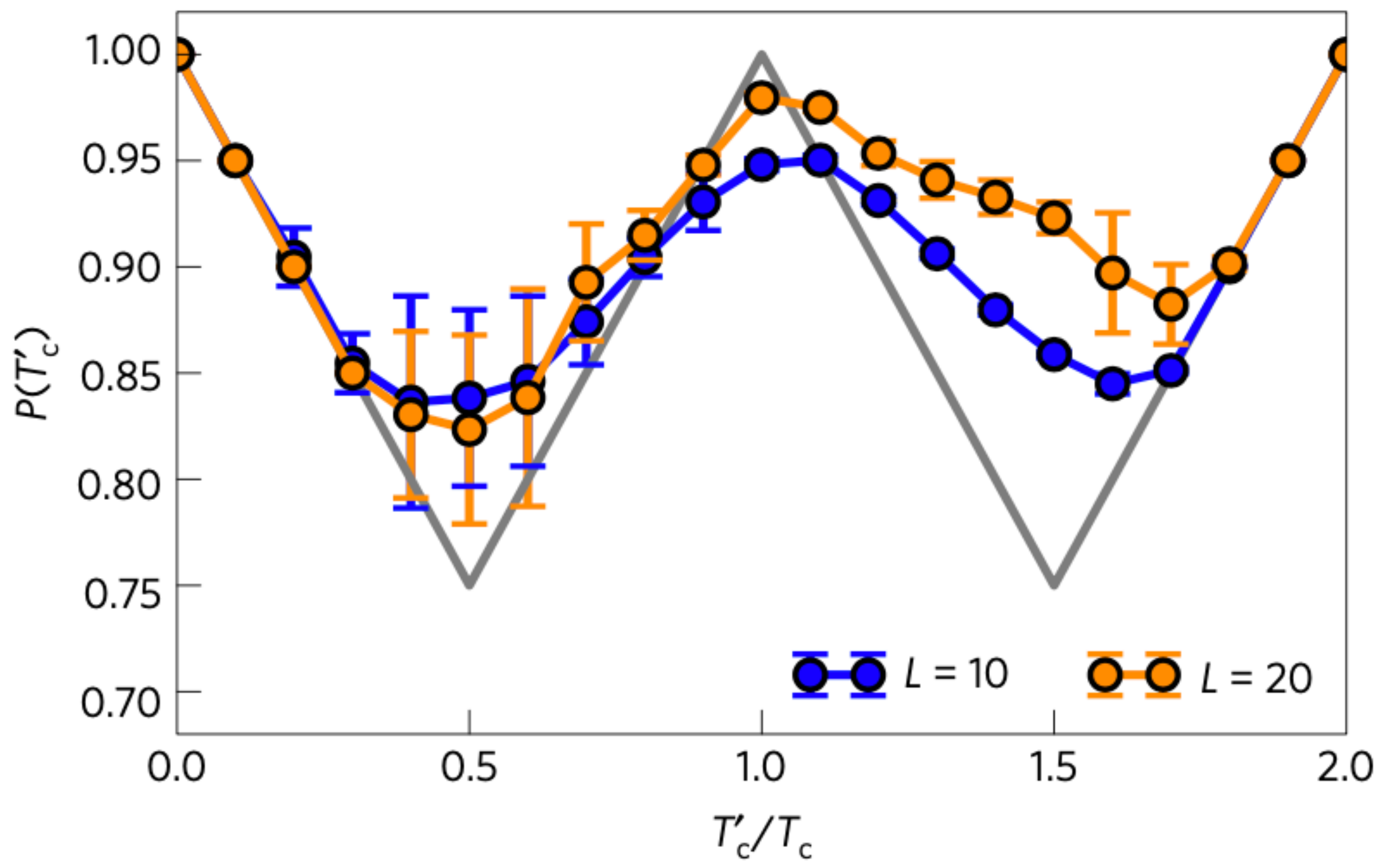




- **Supervised learning**
- **Intro: neural networks**
- **Classifying phases of matter**

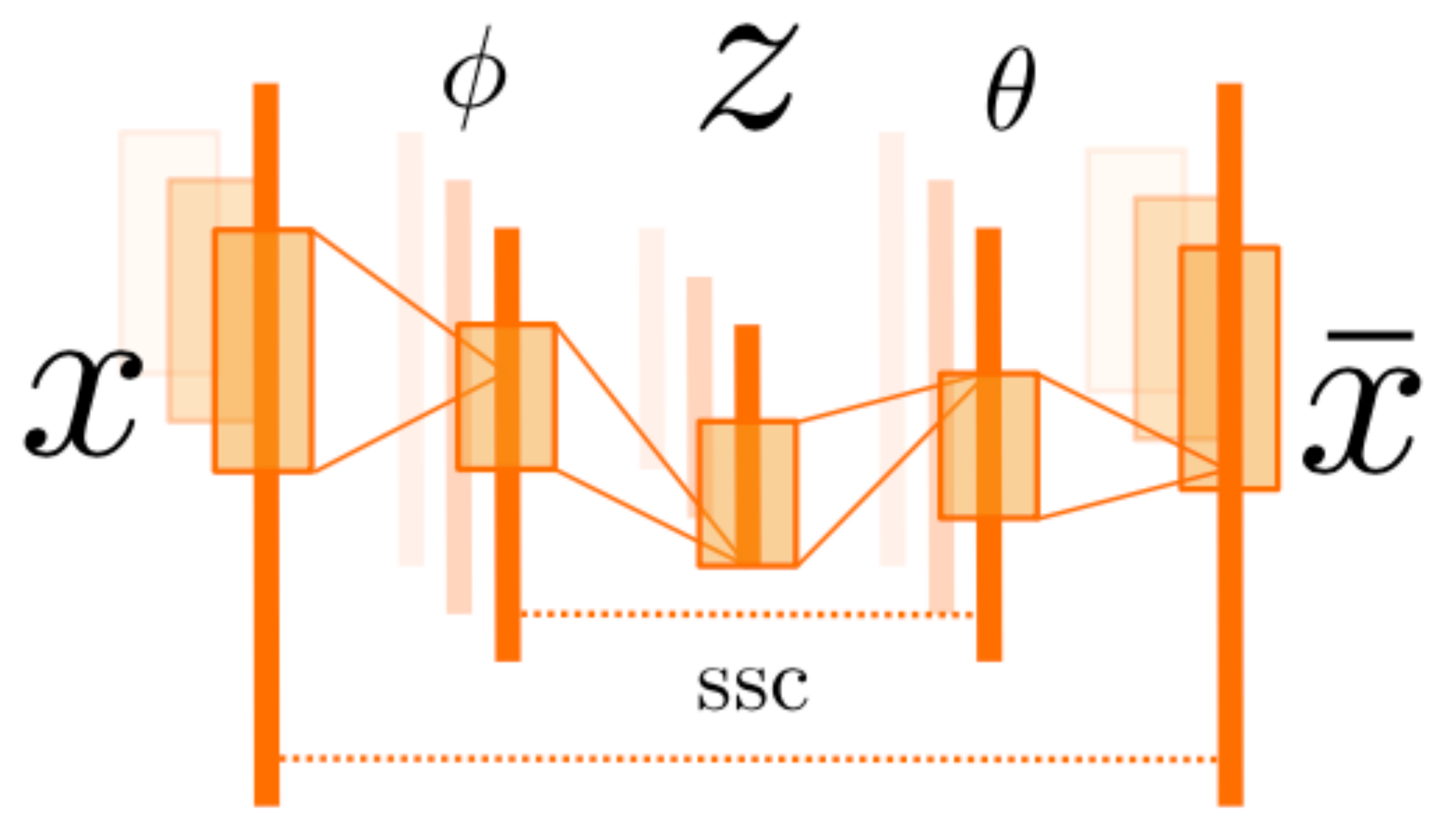
Carrasquilla and Melko, Nat. Phys. 2017

2 - Unsupervised learning of phase transitions



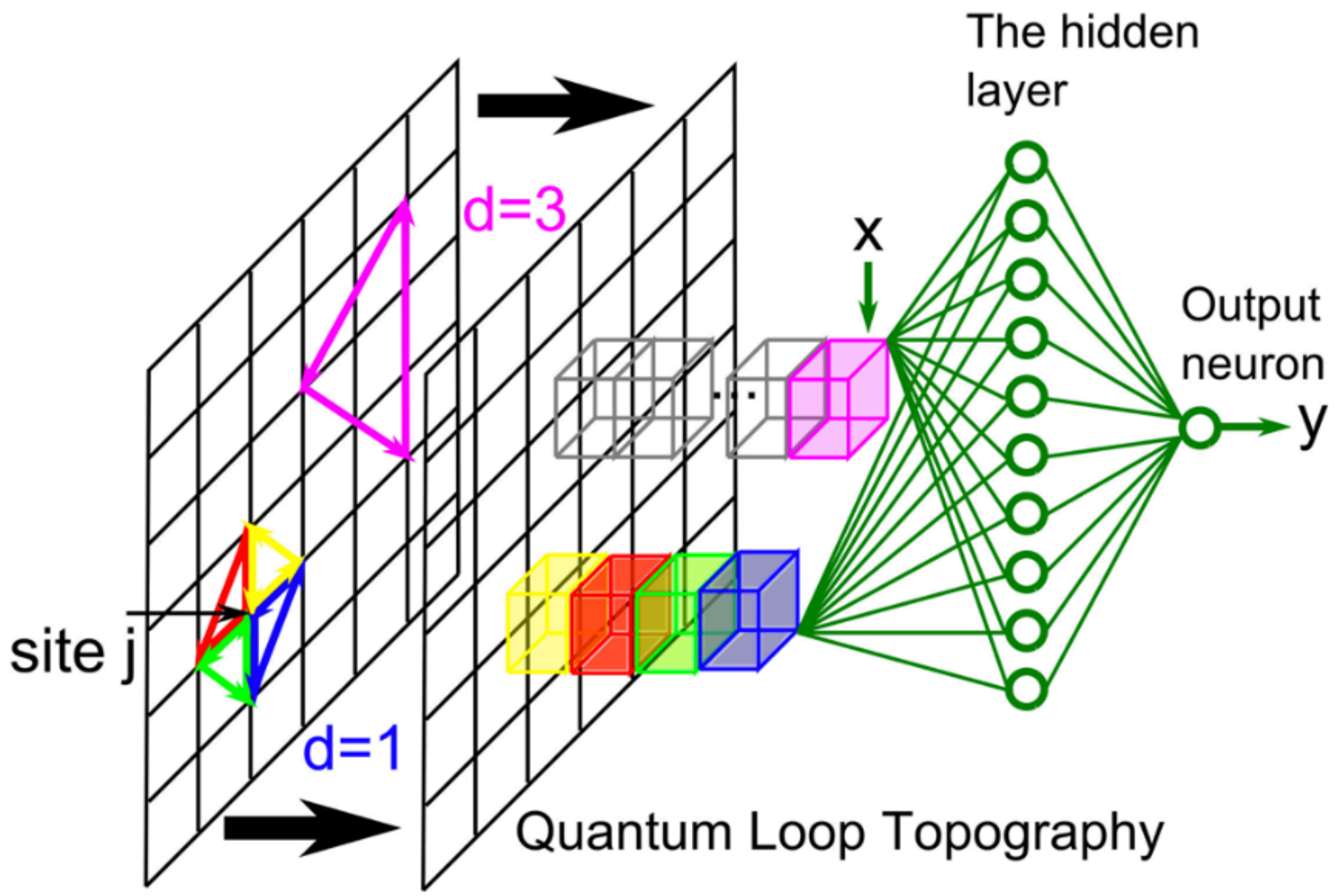
Van Nieuwenburg *et al.*, Nat. Phys. 2017

Kottmann *et al.*, Phys. Rev. Lett. 2020

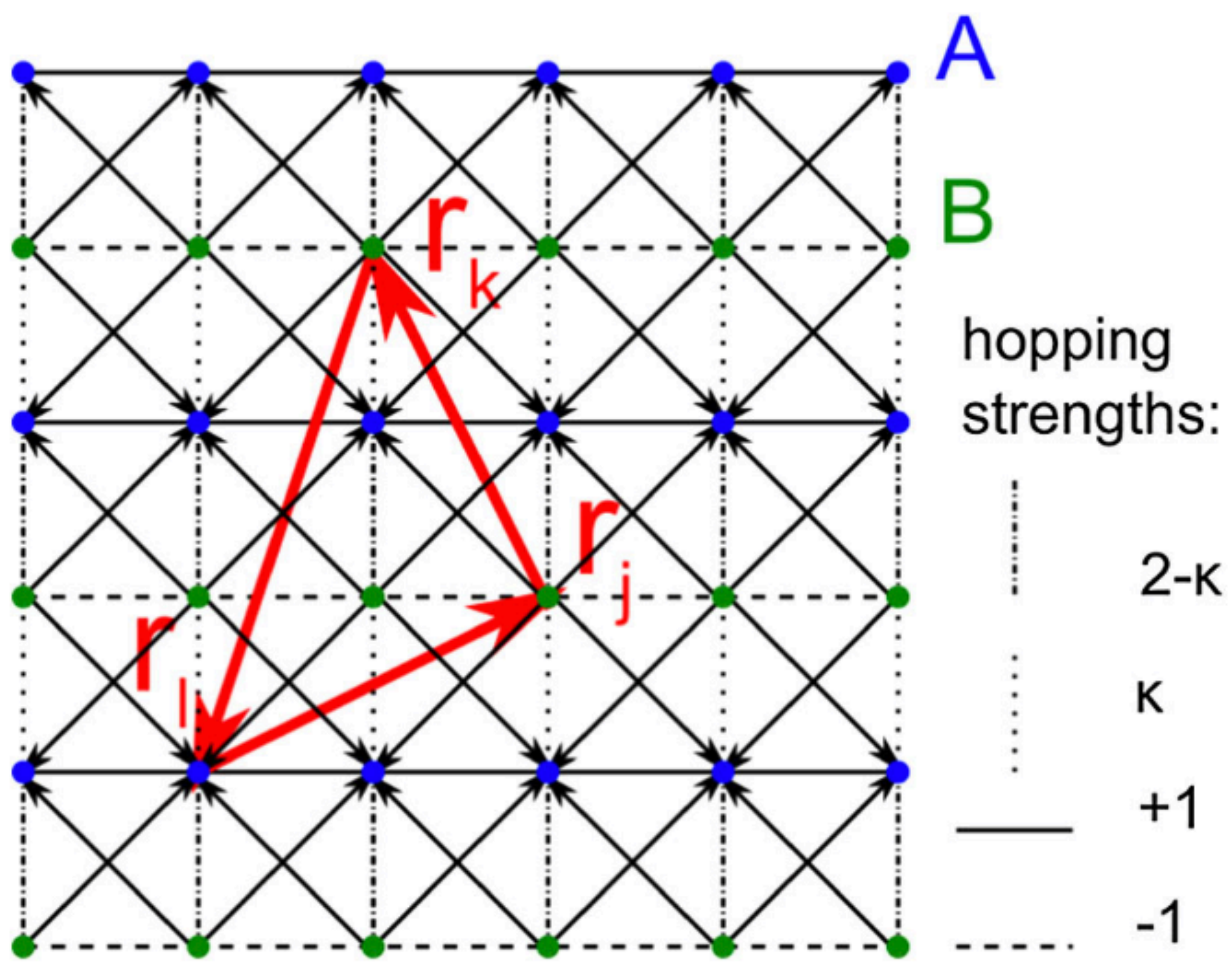


- **Unsupervised learning**
- **"Learning by confusion"**
- **Autoencoder networks**
- **Identifying phase transitions**

3 - Physics-informed learning of topological phases

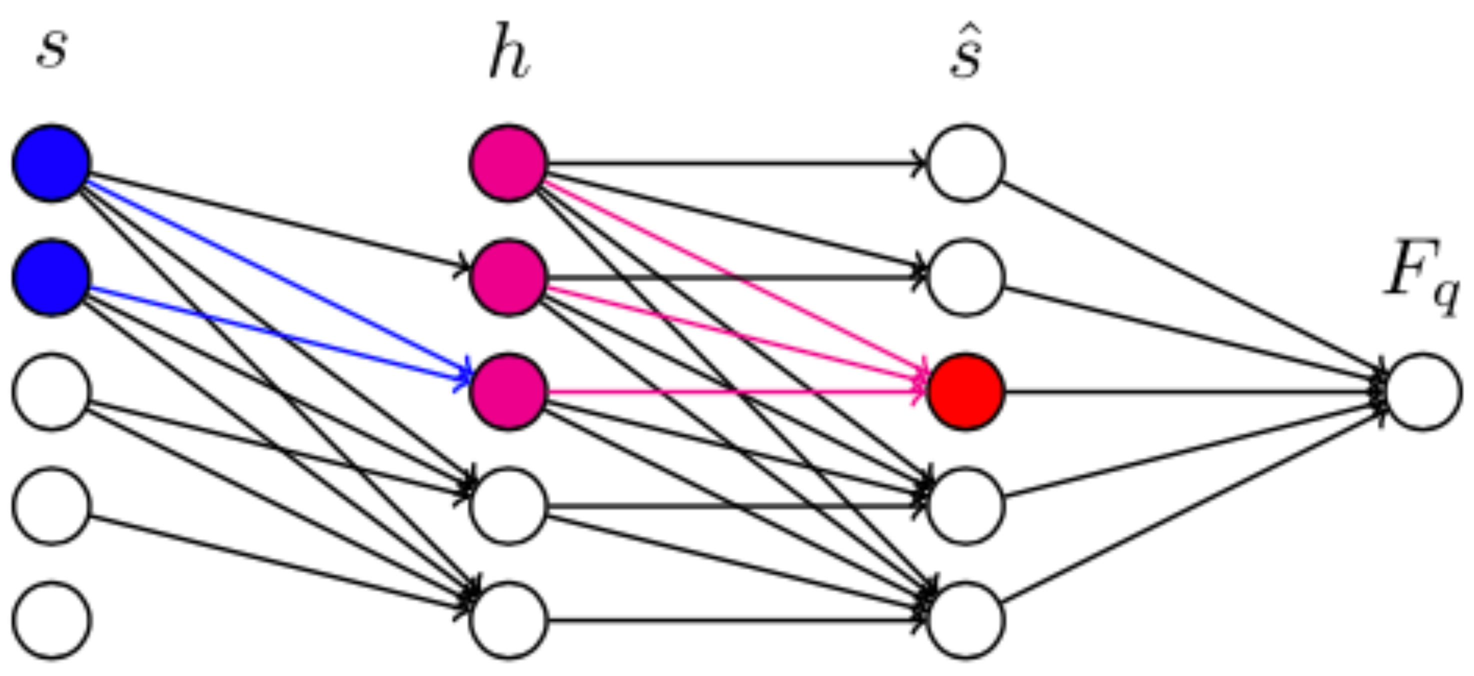


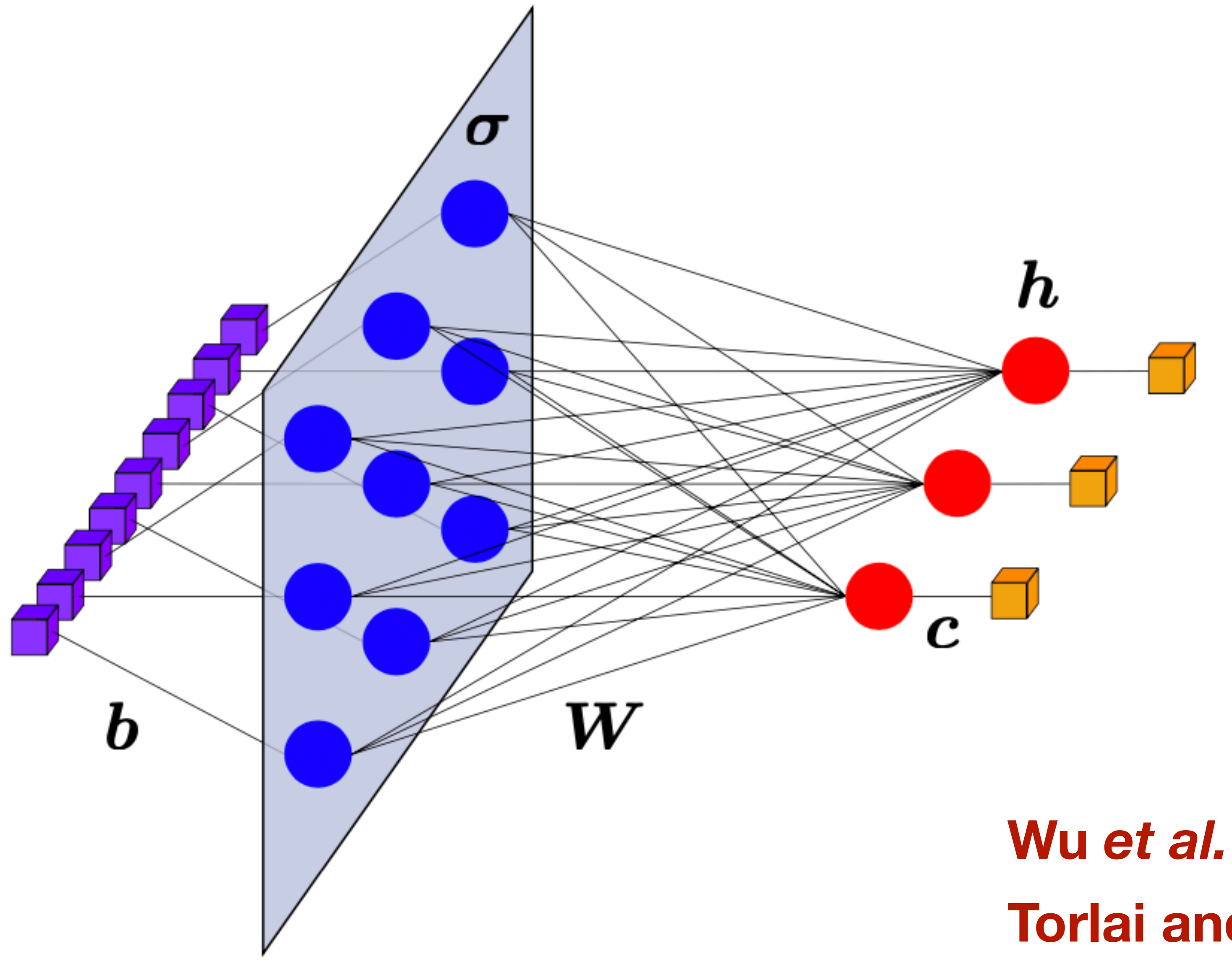
Zhang and Kim, Phys. Rev. Lett. 2017



- **Supervised learning**
- **Incorporating physics in neural networks**
- **Topological phases**

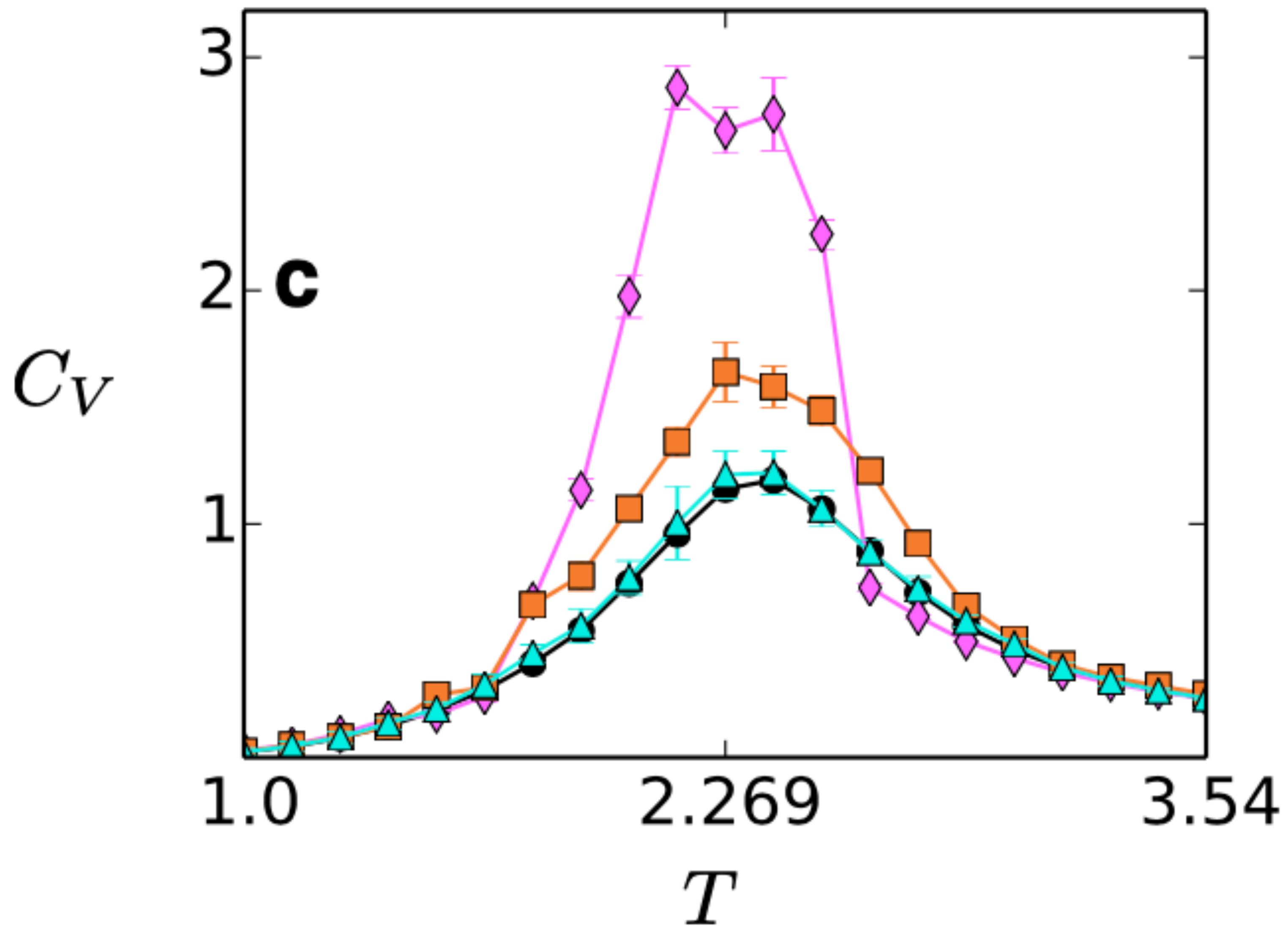
4 - Generative modelling for statistical physics





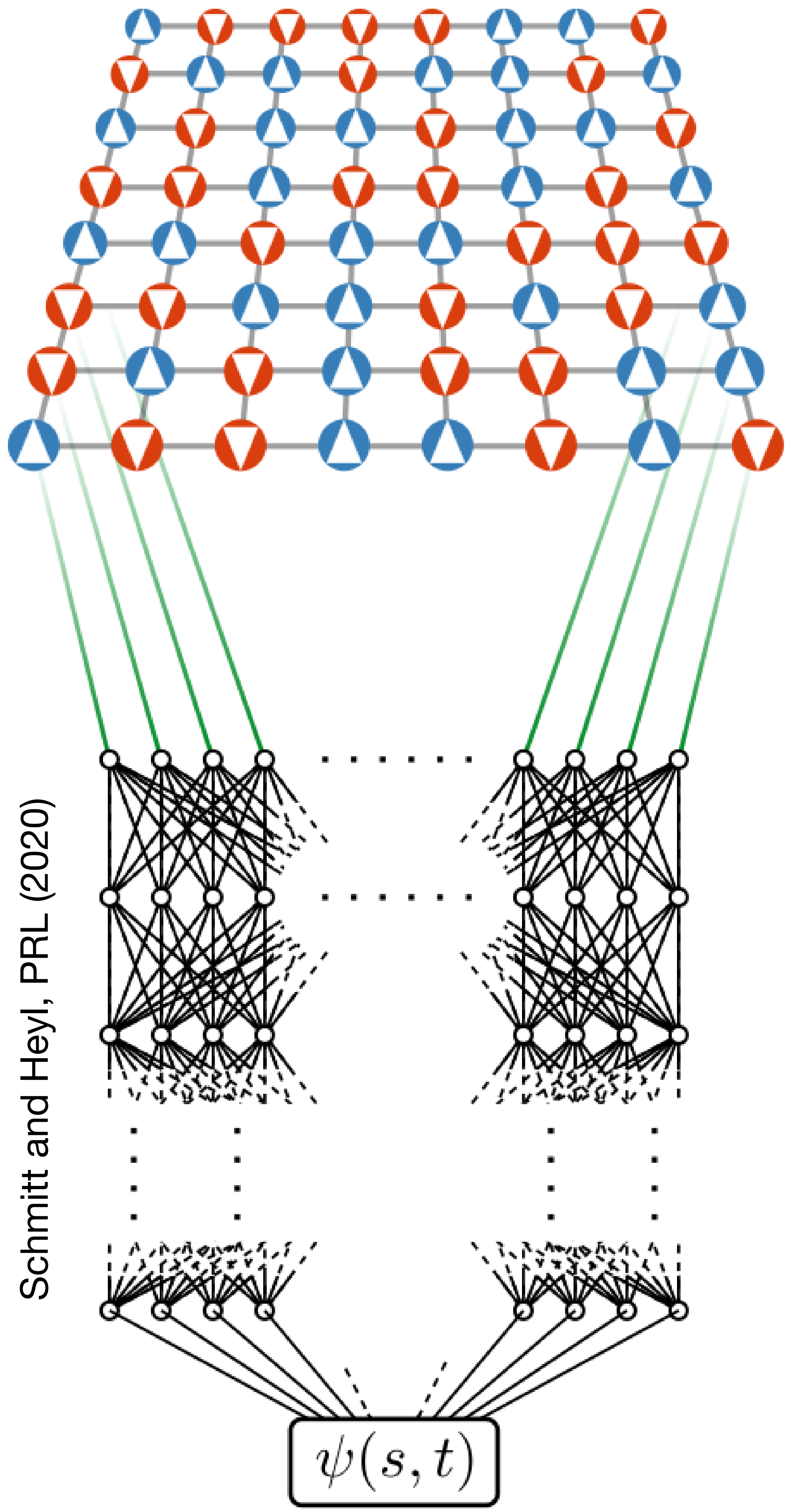
Wu *et al.*, Phys. Rev. Lett. 2019

Torlai and Melko, Phys. Rev. B 2016

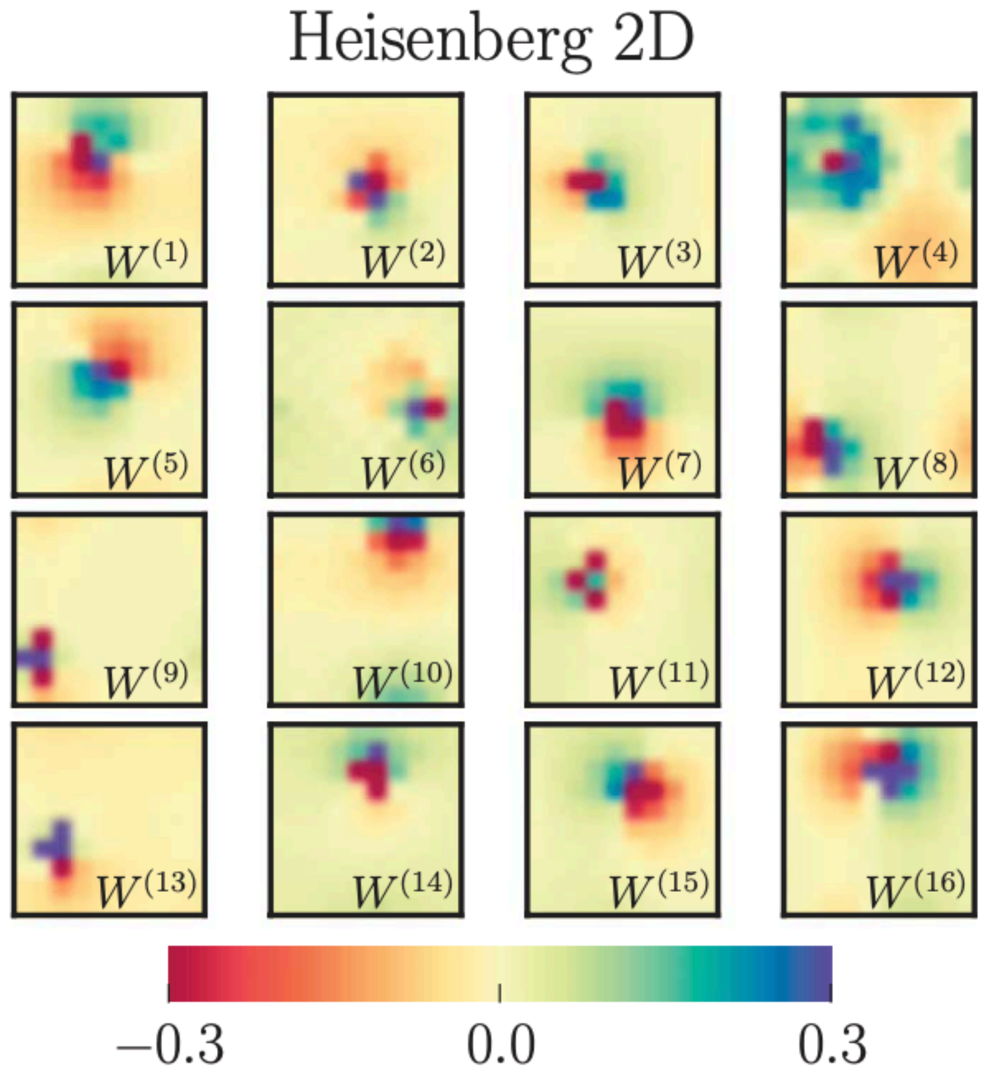


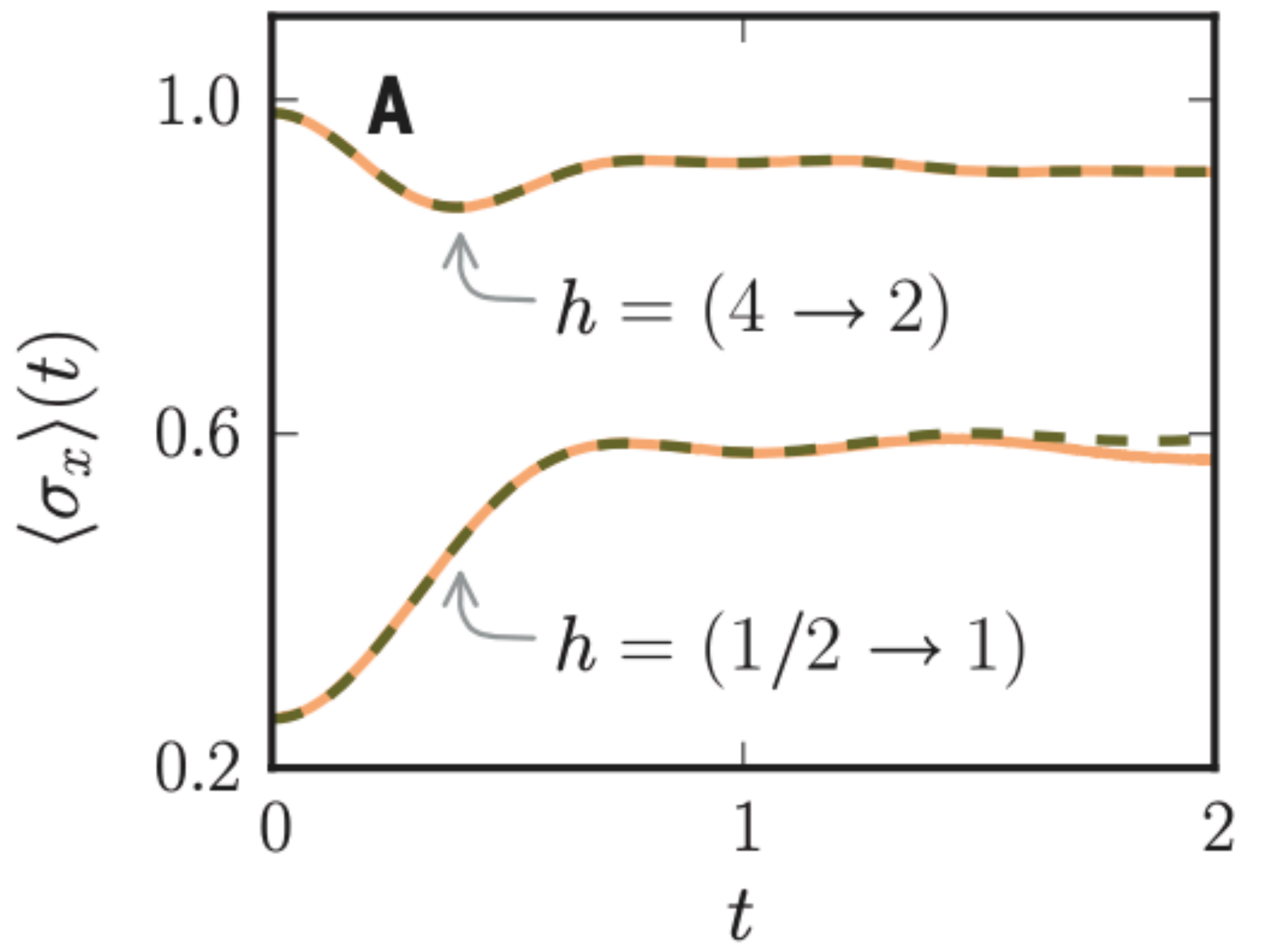
- Unsupervised learning of probabilities
- Generative models: Restricted Boltzmann machine, recurrent neural network
- Statistical physics and thermodynamics (classical)

5 - Neural network wave functions



Schmitt and Heyl, PRL (2020)

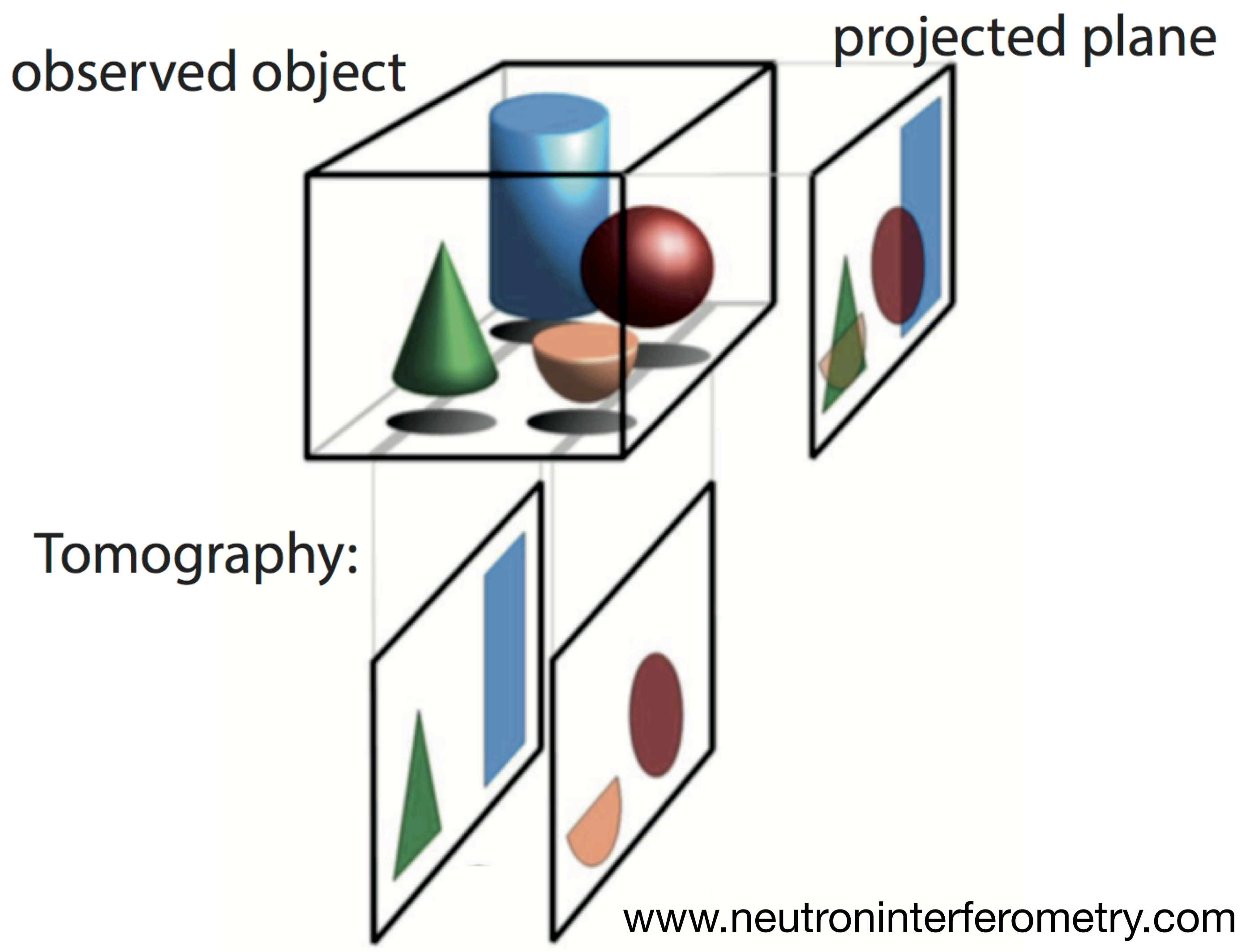


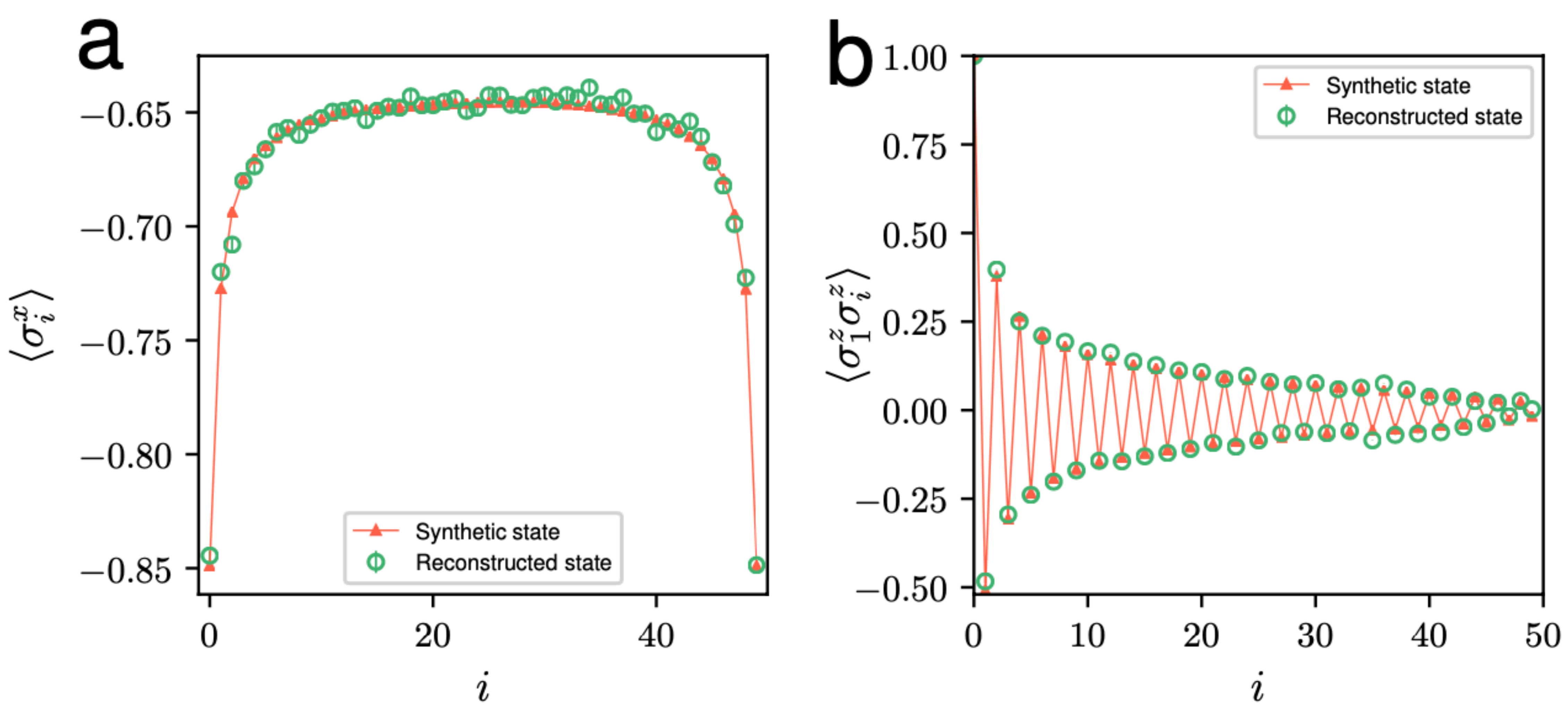


Carleo and Troyer, Science 2017

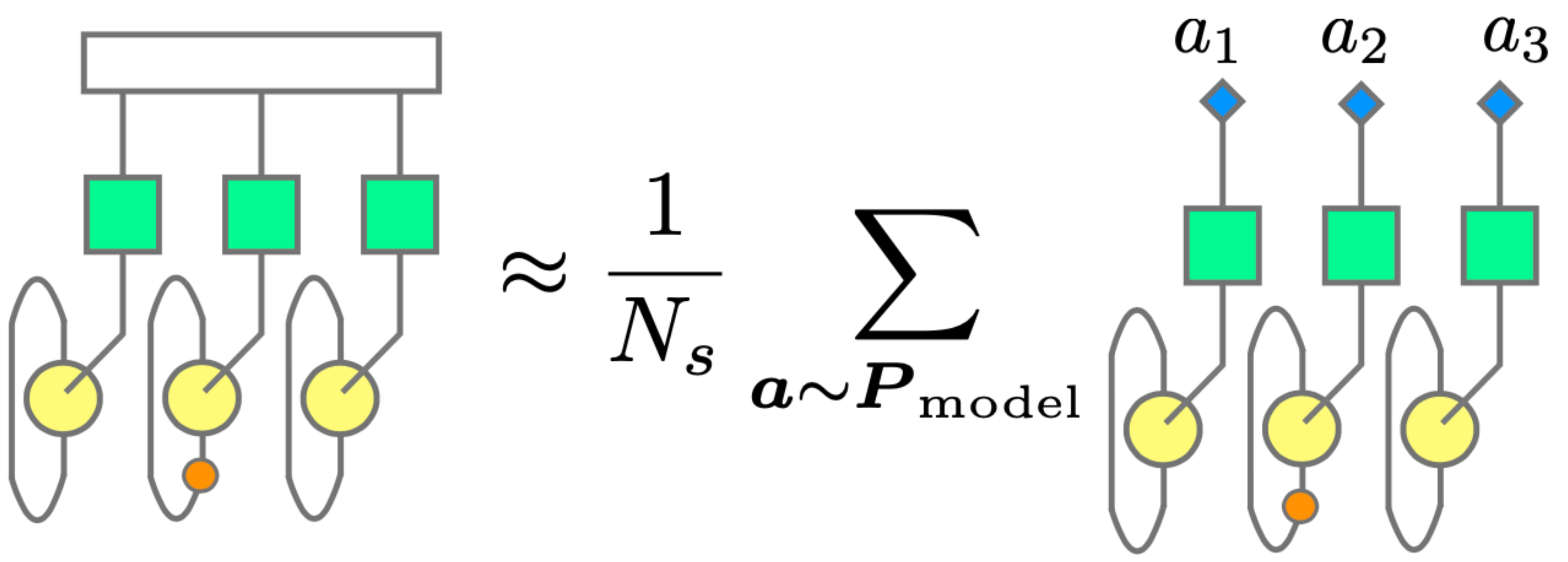
- Encoding quantum wave functions in neural networks
- Low-energy physics
- Non-equilibrium dynamics

6 - Neural network quantum state tomography



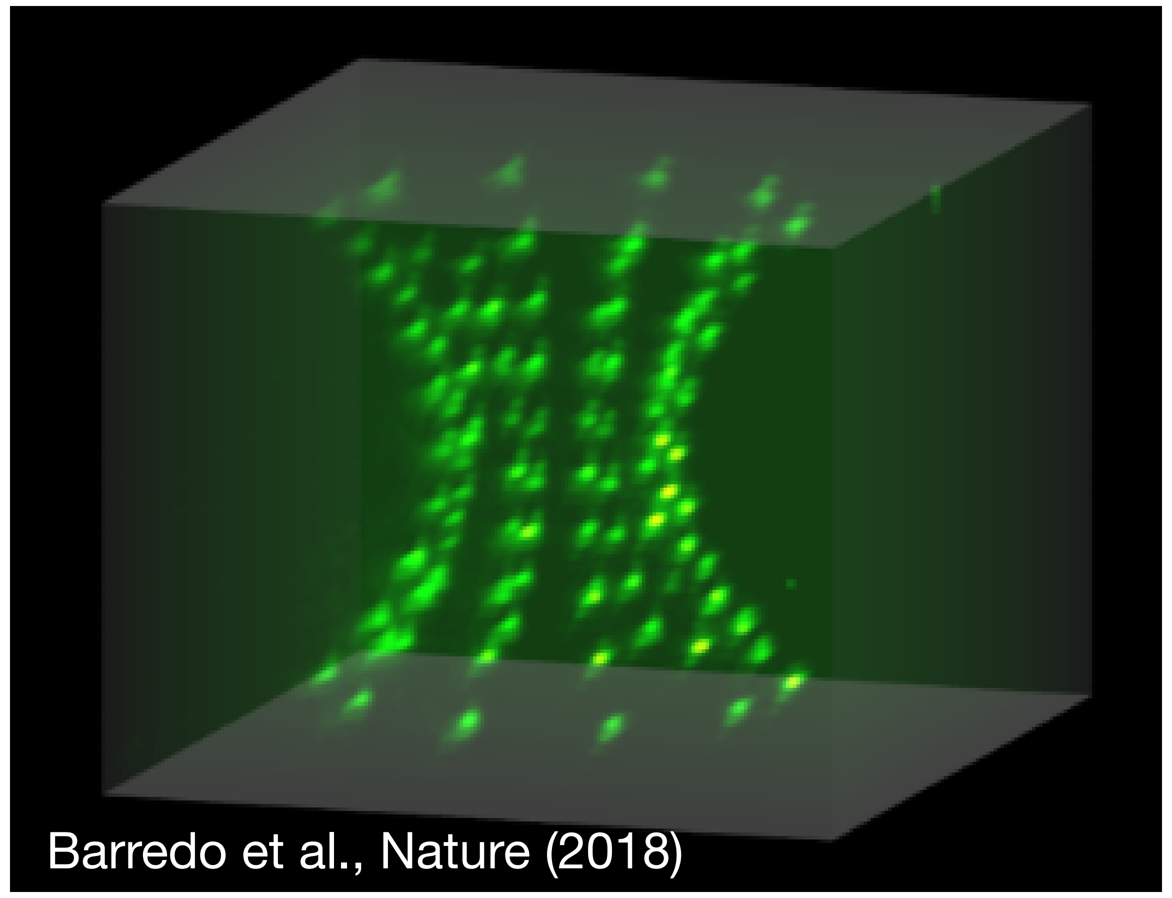


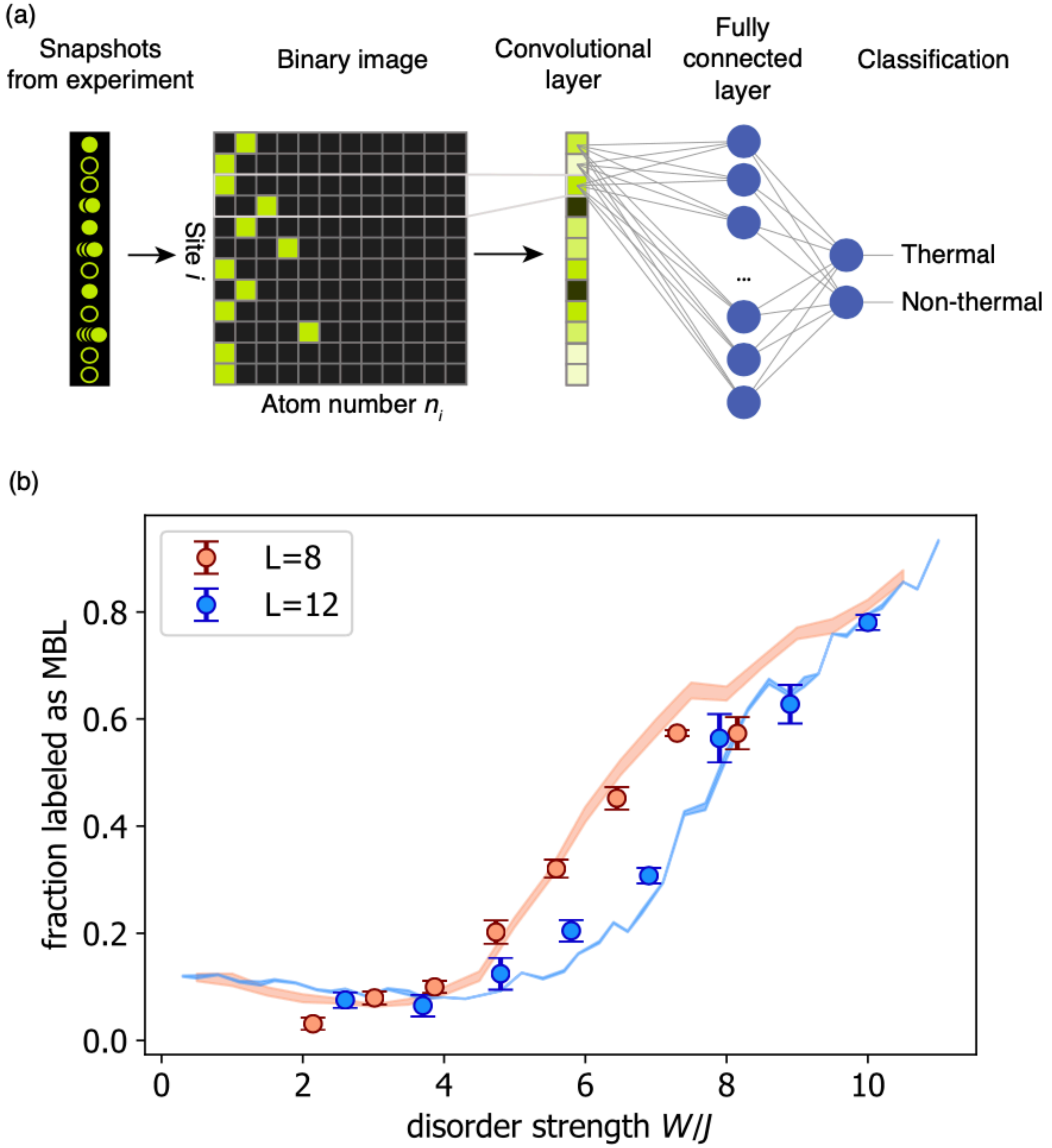
- **Generative modelling of quantum states**
- **Reconstructing states from observations**
- **POVM-representation of density matrix (quantum info)**



Carrasquilla *et al.*, Nat. Mach. Intell. 2019

7 - Machine learning to analyze experimental data

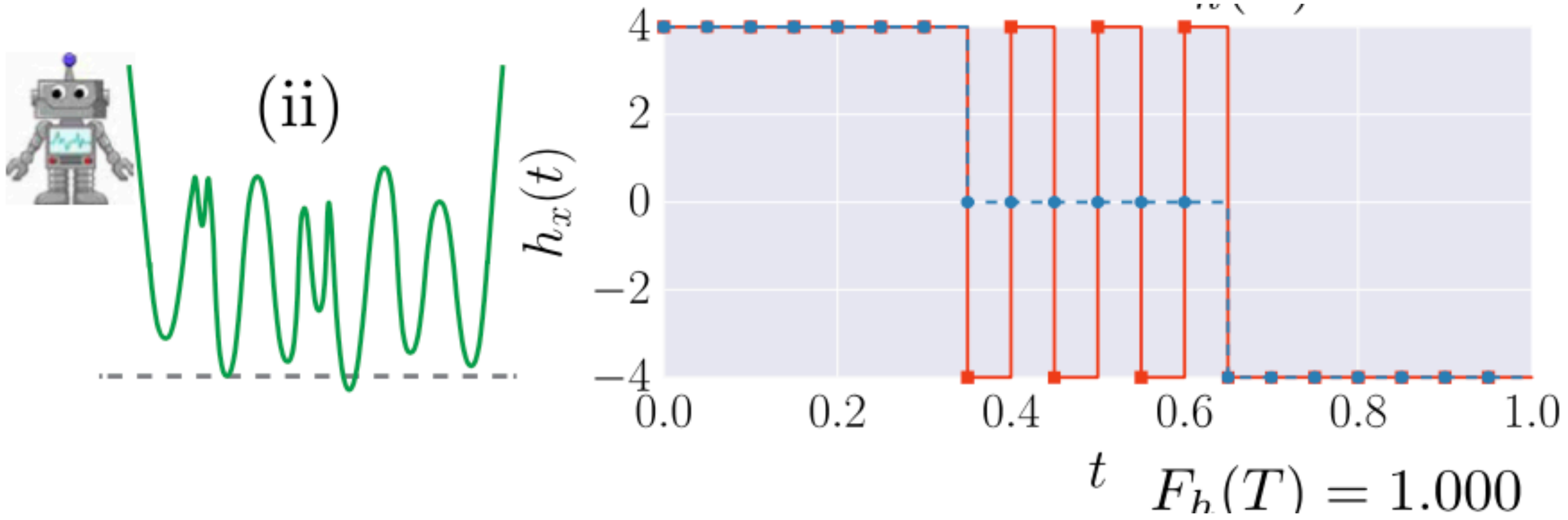


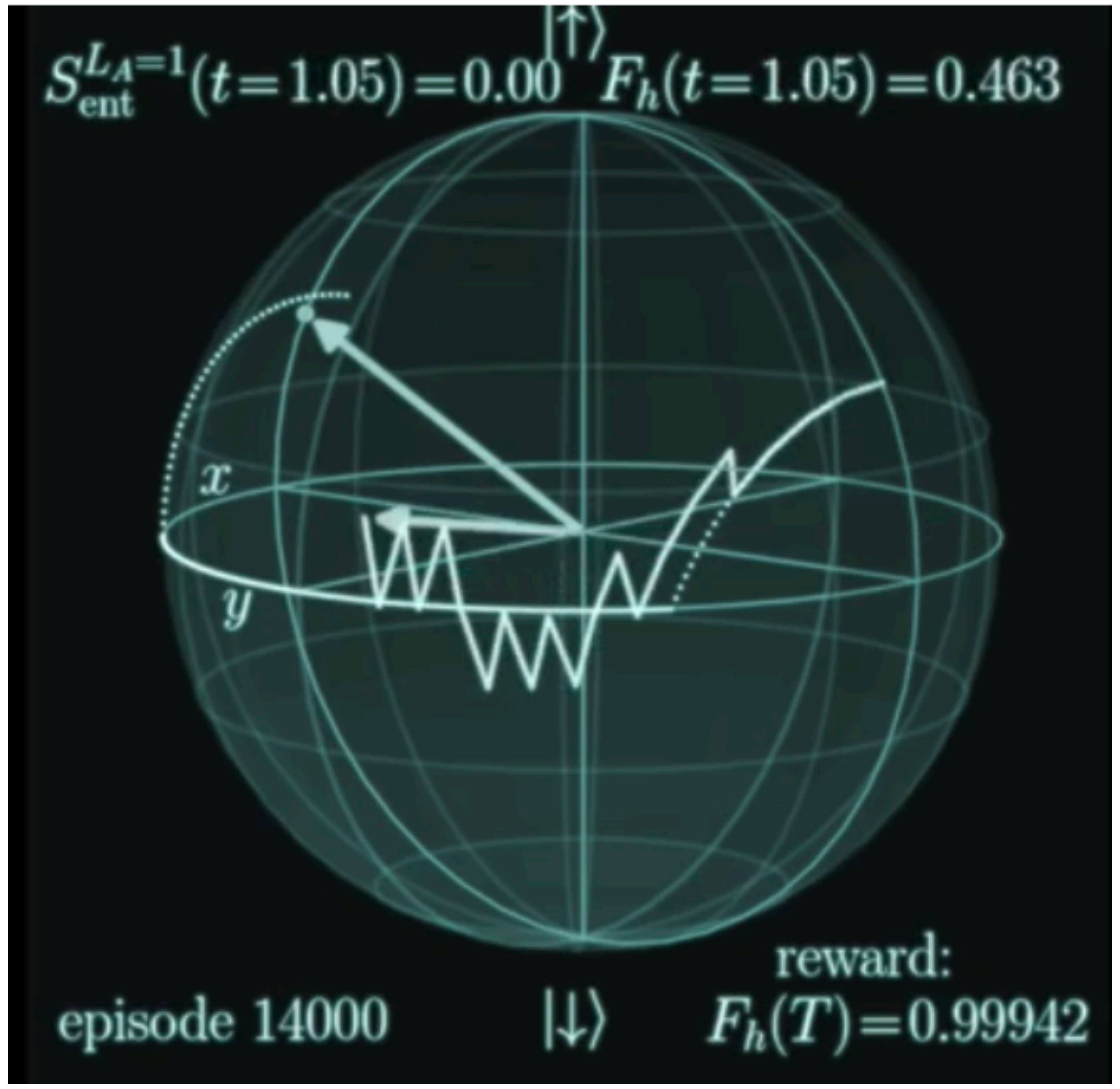


- ▶ **Exemplary applications for data analysis**
- ▶ **Interpretable machine learning**
- ▶ **Data from quantum simulators**

Bohrdt *et al.*, arXiv:2011.03474 / arXiv:2012.11586

8 - Reinforcement learning for quantum control

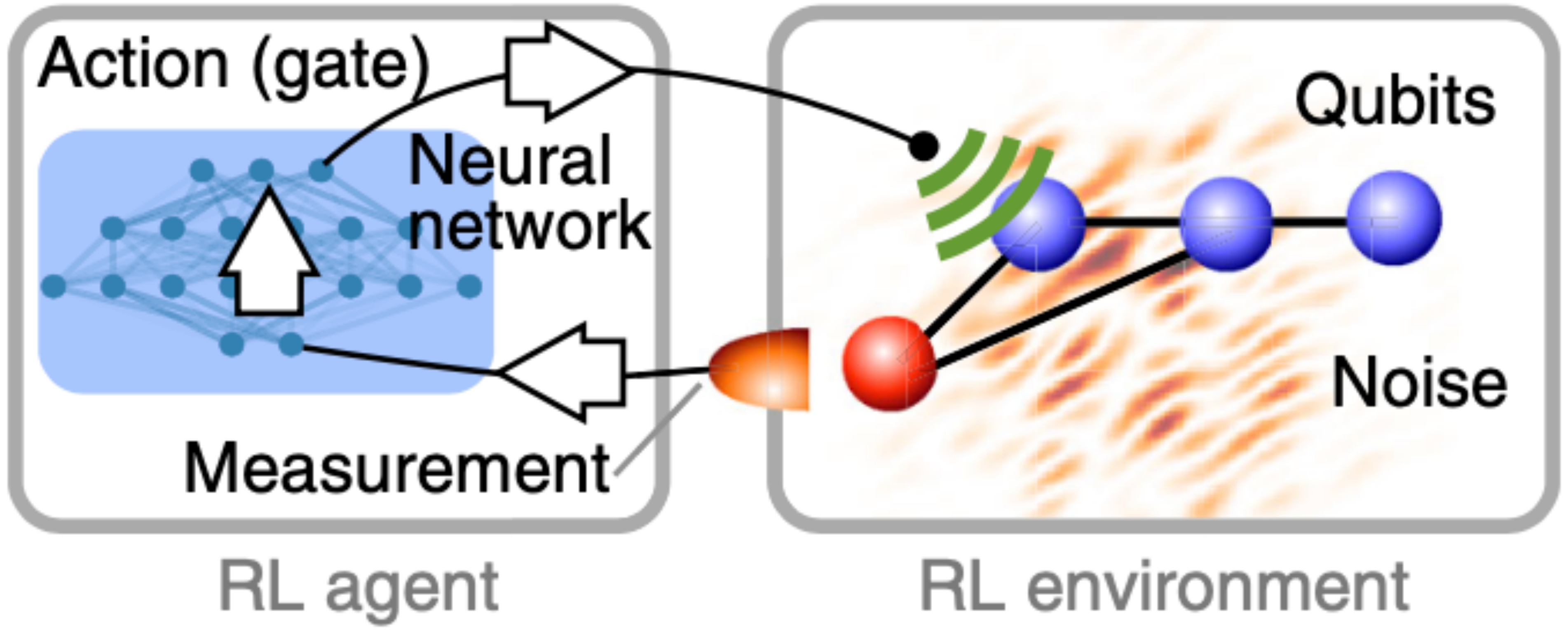


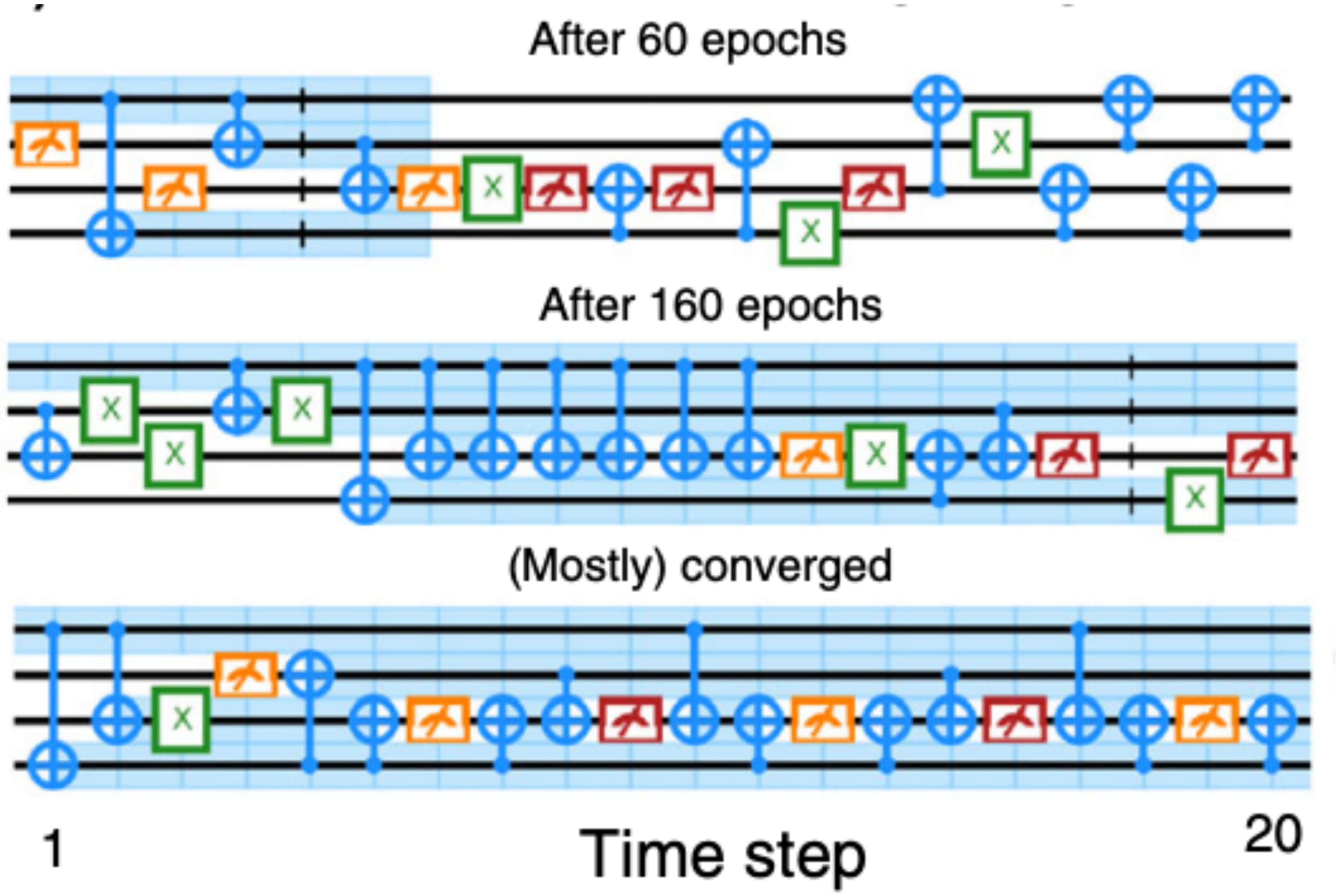


- Reinforcement learning
- Discovering control strategies
- Different phases in the control space

Bukov *et al.*, Phys. Rev. X 2018

9 - Reinforcement learning quantum error correction

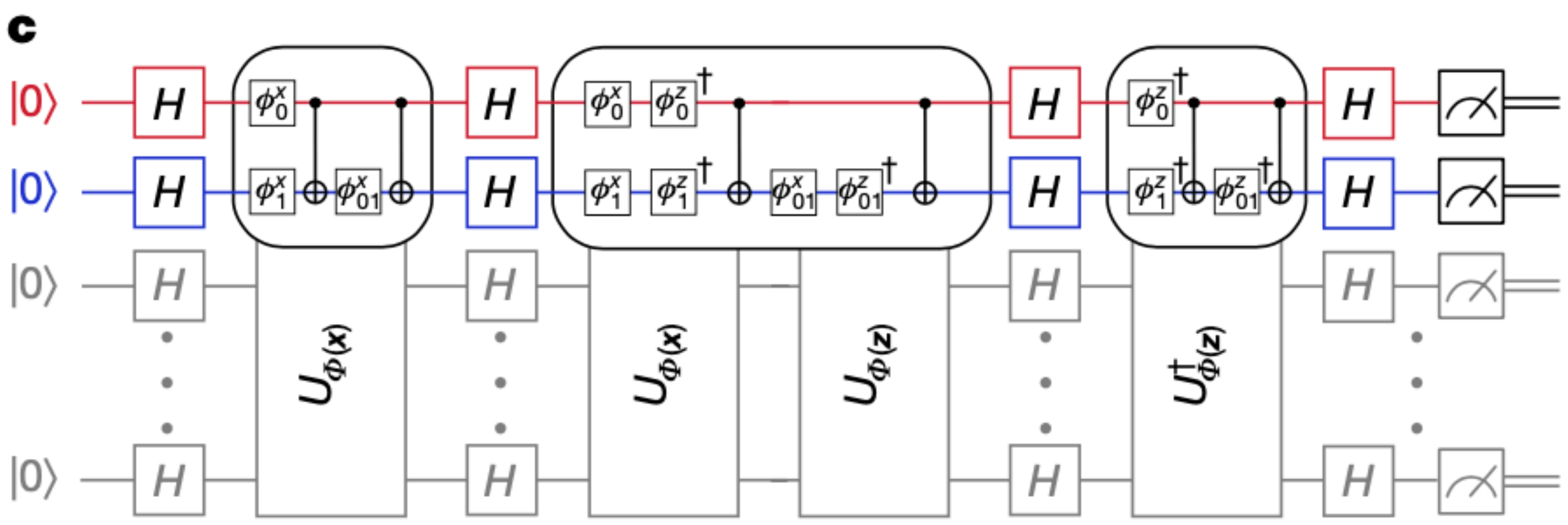


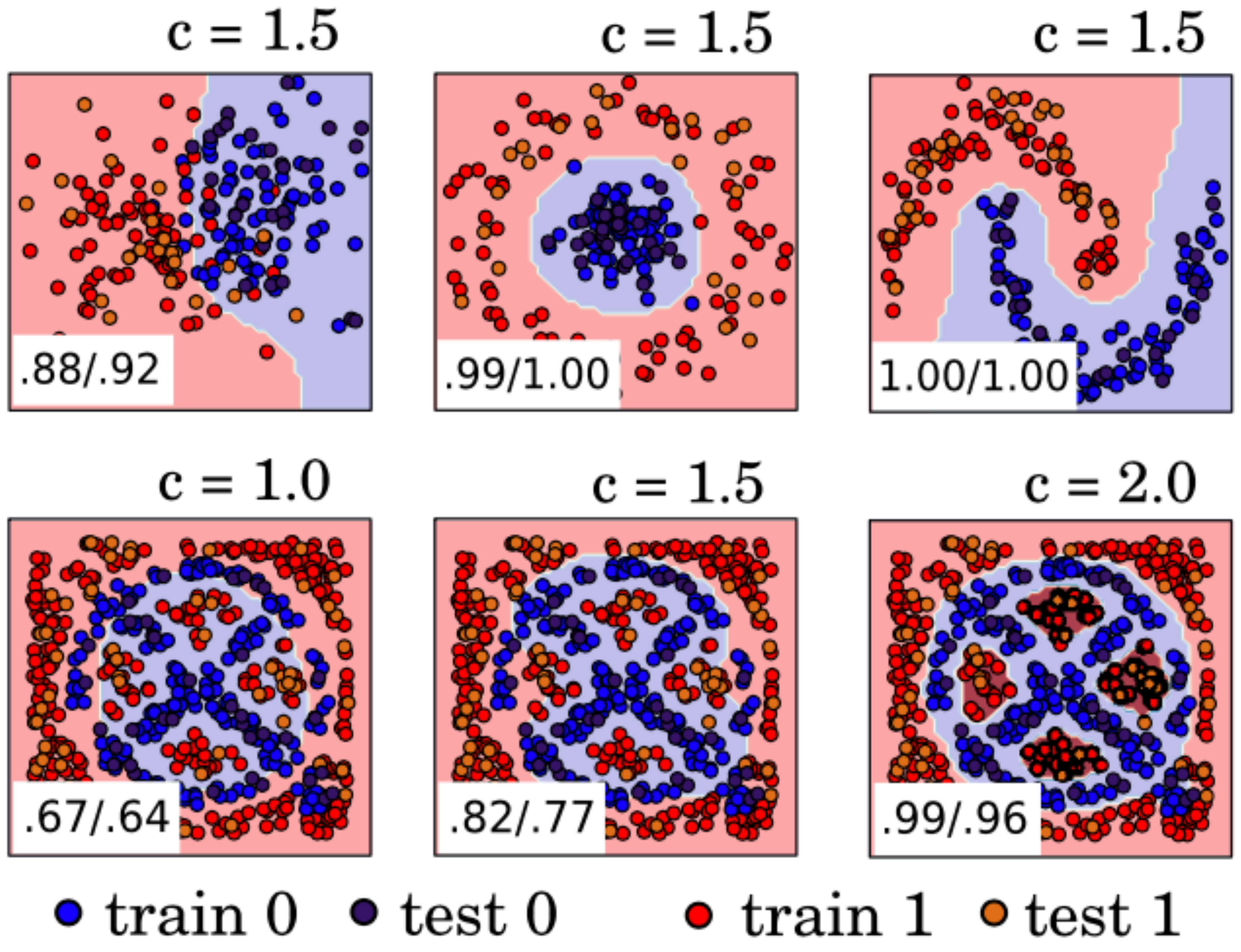


- Reinforcement learning
- Teacher-student
- Quantum error correction

Fösel *et al.*, Phys. Rev. X 2018

10 - Quantum machine learning

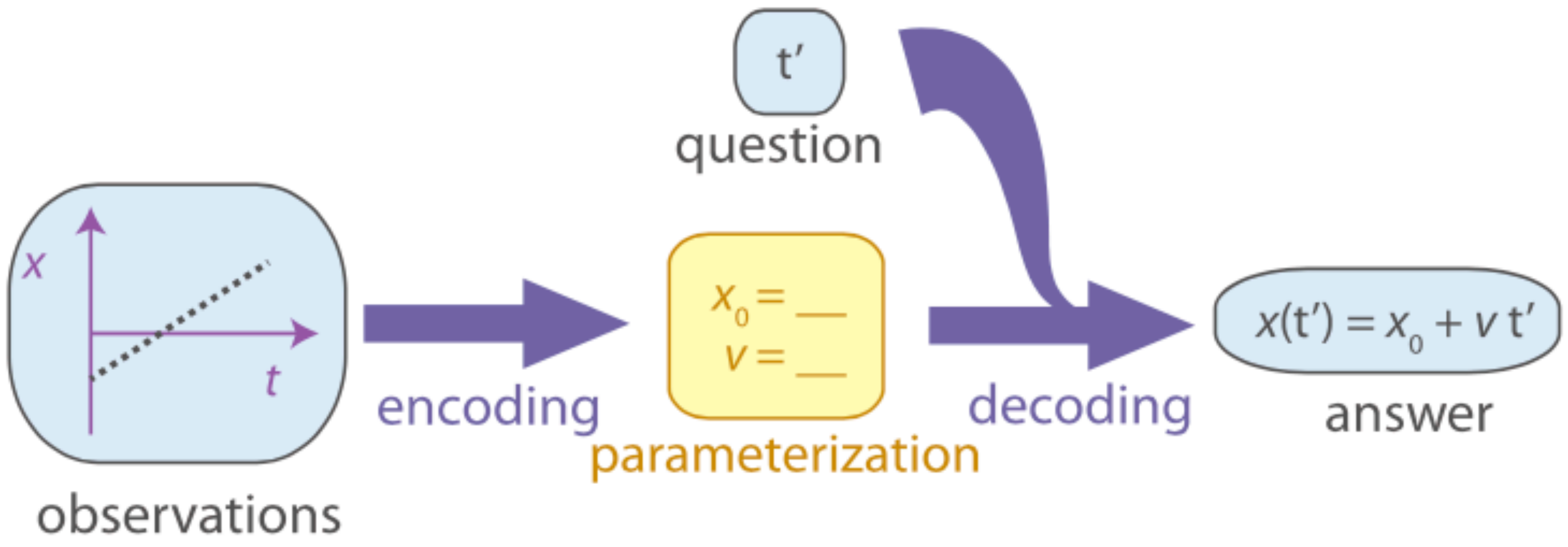


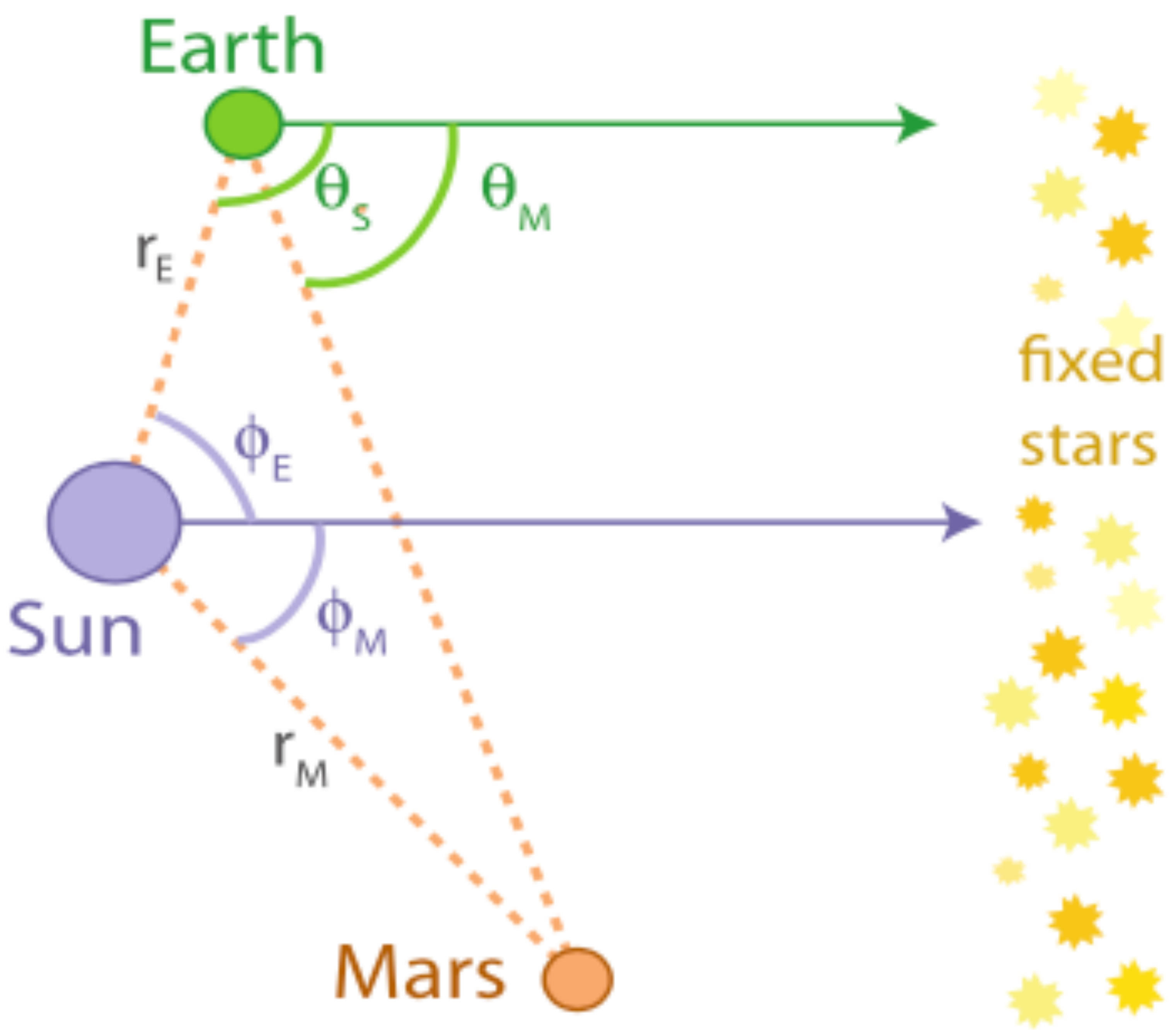


- **Machine learning on quantum computers**
- **Variational quantum circuits**
- **Quantum advantage?**

Schuld and Killoran, Phys. Rev. Lett. 2019
Havlíček *et al.*, Nature 2019

11 - Discovering physical concepts





- Unsupervised learning
- Variational autoencoder
- Extracting information about physical concepts (interpretable ML)

Iten *et al.*, Phys. Rev. Lett. 2020

Schedule

1 - Supervised learning of many-body phases (3.5.)

2 - Unsupervised learning of phase transitions (10.5.)

3 - Physics-informed learning of topological phases (17.5.)

4 - Generative modelling for statistical physics (31.5.)

5 - Neural network wave functions (7.6.)

6 - Neural network quantum state tomography (14.6.)

7 - Machine learning to analyze experimental data (21.6.)

8 - Reinforcement learning for quantum control (28.6.)

9 - Reinforcement learning quantum error correction (5.7.)

10 - Quantum machine learning (12.7.)

11 - Discovering physical concepts (19.7.)