

## PHYSIKALISCHES KOLLOQUIUM

**Wintersemester 2026/27**

Das Kolloquium findet (soweit nicht anders angegeben) **jeweils montags um 14:15 Uhr im Röntgen-Hörsaal** des Physikalischen Instituts, Hubland Campus Süd, Universität Würzburg **und online via Zoom** statt.

Zugangsdaten siehe <https://www.physik.uni-wuerzburg.de/aktuelles/veranstaltungen-aus-der-physik/physikalisches-kolloquium/>

**30.11.2026**

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### **Physical Learning Machines**

#### **Abstract**

The increasing size of neural networks for deep learning applications and their energy consumption create a need for alternative more efficient hardware. The field of neuromorphic computing aims to address this challenge by replacing our digital artificial neural networks with a physical network, for example, using optics, that performs the required mathematical operations.

Current proposals and implementations rely on physical nonlinearities or optoelectronic conversion to realise the required nonlinear activation function. However, there are considerable challenges with these approaches related to power levels, control, energy efficiency and delays. In my talk, I will give an introduction to computing with physical systems and give specific examples from our own research.

In the first part of my talk, I will present a scheme [1] for a physical neural network that relies on linear wave scattering and yet achieves nonlinear processing with high expressivity. The key idea is to encode the input in physical parameters that affect the scattering processes. Moreover, we show that gradients needed for training can be directly measured in scattering experiments. We propose an implementation using integrated photonics based on racetrack resonators, which achieves high connectivity with a minimal number of waveguide crossings. Our work introduces an easily implementable approach to neuromorphic computing that can

be widely applied in existing state-of-the-art scalable platforms, such as optics, microwave and electrical circuits.

In the second part of my talk, I will discuss physical training strategies for neuromorphic systems [2,3,4]. Physically extracting the gradients required for training remains challenging as generic approaches only exist in certain cases. Equilibrium propagation (EP) is such a procedure that has been introduced and applied to classical energy-based models which relax to an equilibrium. Here, I will show a direct connection between EP and Onsager reciprocity and exploit this to derive a quantum version of EP [5]. This can be used to optimize loss functions that depend on the expectation values of observables of an arbitrary quantum system. Specifically, I will illustrate this new concept with supervised and unsupervised learning examples in which the input or the solvable task is of quantum mechanical nature, e.g., the recognition of quantum many-body ground states, quantum phase exploration, sensing and phase boundary exploration. We propose that in the future quantum EP may be used to solve tasks such as quantum phase discovery with a quantum simulator even for Hamiltonians which are numerically hard to simulate or even partially unknown. Our scheme is relevant for a variety of quantum simulation platforms such as ion chains, superconducting qubit arrays, neutral atom Rydberg tweezer arrays and strongly interacting atoms in optical lattices.

- [1] C.C. Wanjura, F. Marquardt. Nat Phys 20, 1434–1440 (2024).
- [2] A. Momeni, B. Rahmani, B. Scellier, et al. Nature 645, 53–61 (2025).
- [3] Q. Wang, C.C. Wanjura, F. Marquardt. Neuromorph Comput Eng 4, 034014 (2024).
- [4] N. Dal Cin, F. Marquardt, C.C. Wanjura. arXiv:2508.11750.
- [5] C.C. Wanjura, F. Marquardt. Nat Commun 16, 6595 (2025).

Für die Dozentinnen bzw. Dozenten der Fakultät

Prof. Dr. Trauzettel, Dr. Ünzelmann, Hr. M. Müller