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# **Millikelvin Confocal Microscopy of Semiconductor Membranes and Filter Functions for Unital Quantum Operations**

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June 24, 2025

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The harmony of the world is made manifest in Form and Number, and the heart and soul and all the poetry of Natural Philosophy are embodied in the concept of mathematical beauty.

– D'Arcy Wentworth Thompson

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# Publications

- [1] Yaiza Aragonés-Soria, René Otten, Tobias Hangleiter, Pascal Cerfontaine, and David Gross. “Minimising Statistical Errors in Calibration of Quantum-Gate Sets.” June 7, 2022. DOI: [10.48550/arXiv.2206.03417](https://doi.org/10.48550/arXiv.2206.03417). (Visited on 06/08/2022). Pre-published.
- [2] Pascal Cerfontaine, Tobias Hangleiter, and Hendrik Bluhm. “Filter Functions for Quantum Processes under Correlated Noise.” In: *Physical Review Letters* 127.17 (Oct. 18, 2021), p. 170403. DOI: [10.1103/PhysRevLett.127.170403](https://doi.org/10.1103/PhysRevLett.127.170403).
- [3] Thomas Descamps, Feng Liu, Sebastian Kindel, René Otten, Tobias Hangleiter, Chao Zhao, Mihail Ion Lepsa, Julian Ritzmann, Arne Ludwig, Andreas D. Wieck, Beata E. Kardynał, and Hendrik Bluhm. “Semiconductor Membranes for Electrostatic Exciton Trapping in Optically Addressable Quantum Transport Devices.” In: *Physical Review Applied* 19.4 (Apr. 28, 2023), p. 044095. DOI: [10.1103/PhysRevApplied.19.044095](https://doi.org/10.1103/PhysRevApplied.19.044095). (Visited on 04/28/2023).
- [4] Thomas Descamps, Feng Liu, Tobias Hangleiter, Sebastian Kindel, Beata E. Kardynał, and Hendrik Bluhm. “Millikelvin Confocal Microscope with Free-Space Access and High-Frequency Electrical Control.” In: *Review of Scientific Instruments* 95.8 (Aug. 9, 2024), p. 083706. DOI: [10.1063/5.0200889](https://doi.org/10.1063/5.0200889). (Visited on 08/12/2024).
- [5] Denny Dütz, Sebastian Kock, Tobias Hangleiter, and Hendrik Bluhm. “Distributed Bragg Reflectors for Thermal Isolation of Semiconductor Spin Qubits.”
- [6] Sarah Fleitmann, Fabian Hader, Jan Vogelbruch, Simon Humpohl, Tobias Hangleiter, Stefanie Meyer, and Stefan van Waasen. “Noise Reduction Methods for Charge Stability Diagrams of Double Quantum Dots.” In: *IEEE Transactions on Quantum Engineering* 3 (2022), pp. 1–19. DOI: [10.1109/TQE.2022.3165968](https://doi.org/10.1109/TQE.2022.3165968).
- [7] Fabian Hader, Jan Vogelbruch, Simon Humpohl, Tobias Hangleiter, Chimezie Eguzo, Stefan Heinen, Stefanie Meyer, and Stefan van Waasen. “On Noise-Sensitive Automatic Tuning of Gate-Defined Sensor Dots.” In: *IEEE Transactions on Quantum Engineering* 4 (2023), pp. 1–18. DOI: [10.1109/TQE.2023.3255743](https://doi.org/10.1109/TQE.2023.3255743).
- [8] Tobias Hangleiter, Pascal Cerfontaine, and Hendrik Bluhm. “Filter-Function Formalism and Software Package to Compute Quantum Processes of Gate Sequences for Classical Non-Markovian Noise.” In: *Physical Review Research* 3.4 (Oct. 18, 2021), p. 043047. DOI: [10.1103/PhysRevResearch.3.043047](https://doi.org/10.1103/PhysRevResearch.3.043047). (Visited on 01/19/2022).
- [9] Tobias Hangleiter, Pascal Cerfontaine, and Hendrik Bluhm. “Erratum: Filter-function Formalism and Software Package to Compute Quantum Processes of Gate Sequences for Classical Non-Markovian Noise [Phys. Rev. Research 3, 043047 (2021)].” In: *Physical Review Research* 6.4 (Oct. 16, 2024), p. 049001. DOI: [10.1103/PhysRevResearch.6.049001](https://doi.org/10.1103/PhysRevResearch.6.049001). (Visited on 10/16/2024).
- [10] Isabel Nha Minh Le, Julian D. Teske, Tobias Hangleiter, Pascal Cerfontaine, and Hendrik Bluhm. “Analytic Filter-Function Derivatives for Quantum Optimal Control.” In: *Physical Review Applied* 17.2 (Feb. 2, 2022), p. 024006. DOI: [10.1103/PhysRevApplied.17.024006](https://doi.org/10.1103/PhysRevApplied.17.024006). (Visited on 02/03/2022).
- [11] Paul Surrey, Julian D. Teske, Tobias Hangleiter, Pascal Cerfontaine, and Hendrik Bluhm. “Data-Driven Qubit Characterization and Optimal Control Using Deep Learning.”
- [12] Kui Wu, Sebastian Kindel, Thomas Descamps, Tobias Hangleiter, Jan Christoph Müller, Rebecca Rodrigo, Florian Merget, Beata E. Kardynał, Hendrik Bluhm, and Jeremy Witzens. “Modeling an Efficient Singlet-Triplet-Spin-Qubit-to-Photon Interface Assisted by a Photonic Crystal Cavity.” In: *Physical Review Applied* 21.5 (May 24, 2024), p. 054052. DOI: [10.1103/PhysRevApplied.21.054052](https://doi.org/10.1103/PhysRevApplied.21.054052). (Visited on 08/21/2024).

# Software

The following open-source software packages were developed (at least partially) during the work on this thesis.

- [1] Tobias Hangleiter, Isabel Nha Minh Le, and Julian D. Teske, *Filter\_functions* version v1.1.3, May 14, 2024. Zenodo. DOI: [10.5281/ZENODO.4575000](https://doi.org/10.5281/ZENODO.4575000).
- [2] Tobias Hangleiter, *Lindblad\_mc\_tools*.
- [3] Tobias Hangleiter, *Mjolnir*.
- [4] Tobias Hangleiter, Simon Humpohl, Max Beer, and René Otten, *Python-Spectrometer* version 2024.11.1, Nov. 21, 2024. Zenodo. DOI: [10.5281/ZENODO.13789861](https://doi.org/10.5281/ZENODO.13789861).
- [5] Tobias Hangleiter, Simon Humpohl, Paul Surrey, and Han Na We, *Qutil* version 2024.11.1, Nov. 21, 2024. Zenodo. DOI: [10.5281/ZENODO.14200303](https://doi.org/10.5281/ZENODO.14200303).

**Part I**

**A FLEXIBLE PYTHON TOOL FOR  
FOURIER-TRANSFORM NOISE  
SPECTROSCOPY**

## **Part II**

# **CHARACTERIZATION AND IMPROVEMENTS OF A MILLIKELVIN CONFOCAL MICROSCOPE**



**Part III**

**OPTICAL MEASUREMENTS OF  
ELECTROSTATIC EXCITON TRAPS IN  
SEMICONDUCTOR MEMBRANES**

# Introduction

1



## Conclusion & outlook

2



## **Part IV**

# **A FILTER-FUNCTION FORMALISM FOR UNITAL QUANTUM OPERATIONS**

# **APPENDIX**

