

Call 2021
Final Evaluation

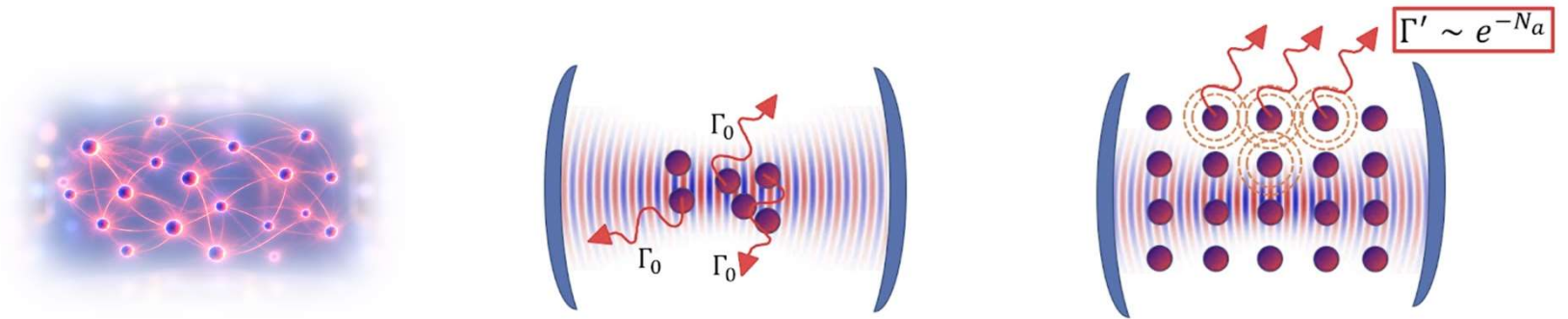


QuSiED

Quantum simulation with engineered dissipation
Lorenzo Rossi (ICFO)

Website: <https://www.qusied-quantera.ijs.si/>

QuSiED- quantum simulation with engineered dissipation



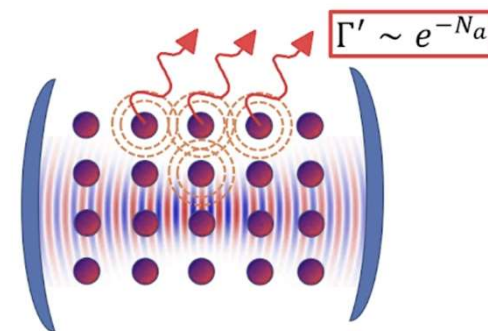
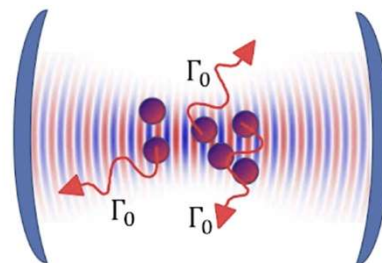
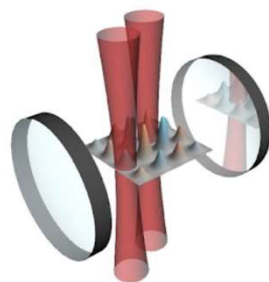
 **GOAL** - quantum simulator with strong, tunable and long-range interactions

 **PLAN** - photon-mediated interactions

 **CHALLENGE** - dissipation (photon loss)

 **OUR SOLUTION** - structured correlated dissipation

QuSiED- quantum simulation with engineered dissipation



PROPOSED IMPLEMENTATION - sub-wavelength tweezer array integrated in a cavity



ADVANTAGE – flexible interactions and strong protection from dissipation



QuSiED collaboration



Slovenia, Austria, Hungary, Germany (2), Spain

2 experimental teams: Hamburg [Hemmerich], Innsbruck [Nägerl]

4 theory teams: Ljubljana [Lenarčič], Budapest [Zaránd]
Barcelona [Chang], Mainz [Marino]



Exchange of know-how in building the experimental setup



Complementary theoretical approaches

- Quantum optics
- Condensed matter
- Quantum information sciences
- Field theory
- Machine learning
- Tensor networks



THEORETICAL DESCRIPTIONS

 **HURDLE:** model long-range light-matter interactions

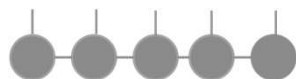
 **APPROACH 1:** non-equilibrium diagrammatics

$$\Gamma_2 \approx \underbrace{\text{Diagram 1} + \text{Diagram 2} + \text{Diagram 3} + \text{Diagram 4} + \dots}_{\Gamma_2^{\text{NLO}} \sim N_s^0}$$

$\Gamma_2^{\text{LO}} \sim N_s$

PRR 6, 043313 (2024),
PRR 6, 043314 (2024)

 **APPROACH 2:** tensor network simulation of open systems

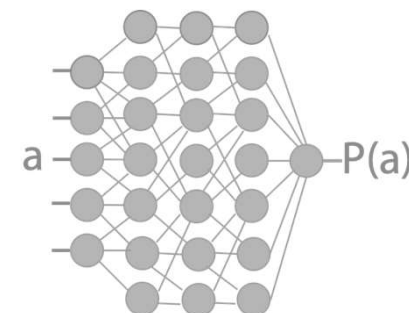


PRB 109, 115120 (2024), PRB 108, L081115 (2023)
PRB 108, 235139 (2023), Quantum 7, 914 (2023).

 **APPROACH 3:** neural network representation of density matrix

$$P^a = \text{Tr}(M^a \rho) \approx P_\theta^a, \quad M^a = M^{a_1} \otimes \dots \otimes M^{a_N}$$

arXiv:2605.04640



 **APPROACH 4:** statistical physics interpretation

Neural network modelling



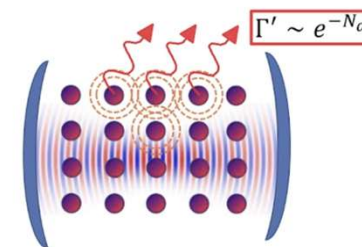
HURDLE: model light-matter dynamics



CHALLENGE: long-range interactions, dissipation, arbitrary geometry



SOLUTION: neural network ansatz - beyond state-of-the-art



	Tensor Networks	Cumulant Expansion	Neural Networks
Long-range interactions	✓	✓	✓
Correlated dissipation	✓	✓	✓
Arbitrary geometry	✗	✓	✓
Controlled error	✓	✗	✓

Lagnese et al.
arXiv:2605.04640



Statistical physics description



HURDLE: physical interpretation of microscopic dynamics

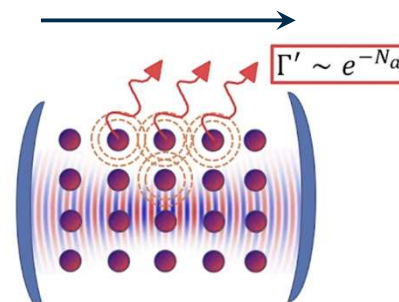


SOLUTION: connection to statistical mechanics

	Neural Networks	Statistical mechanics
Microscopic modelling	✓	✗
Physical interpretation	✗	✓

Physical understanding

Dissipation = foe



Dissipation = ally



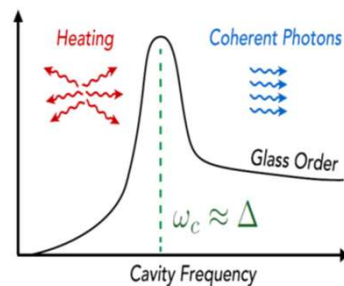
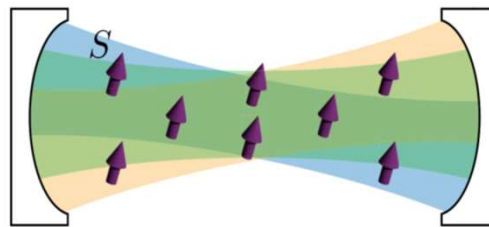
“cooling” mechanism

EXOTIC PHYSICS

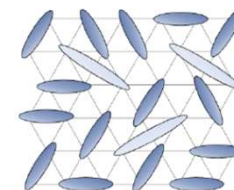
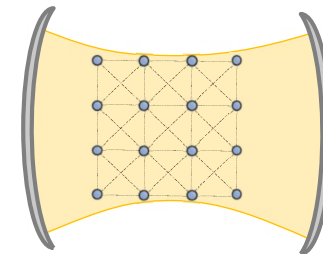


SPIN GLASSES AND SPIN LIQUIDS:

- interplay of long-range interactions and dissipation
- important for optimization problems
- emergent locality and structured non-locality



Hosseiniabadi et al.
PRR 6, 043313 (2024)



Mann et al.
arXiv:2512.05630



QUANTUM MEMORY FOR LIGHT

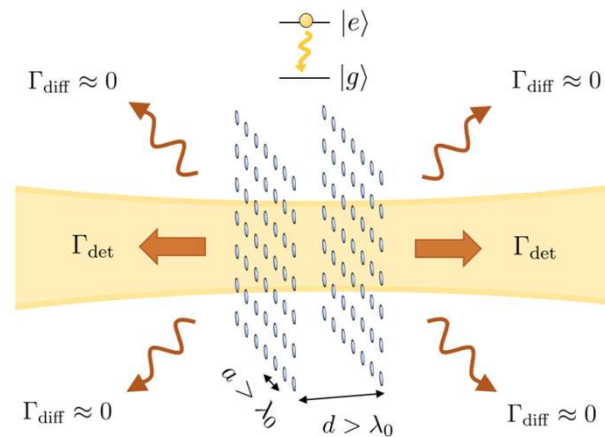


CHALLENGE: efficient quantum memories



SOLUTION: ordered super-wavelength arrays

- 1% error with ~ 100 atoms
- suppressed emission into unwanted directions



Mann et al. [arXiv:2402.06439](https://arxiv.org/abs/2402.06439)



CAVITY-TWEEZER SETUP (Innsbruck)



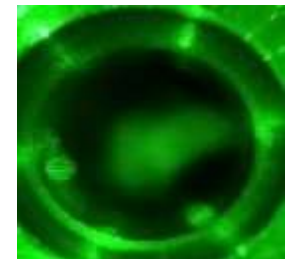
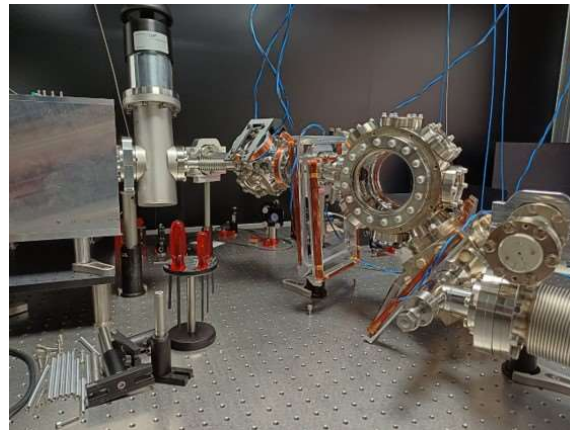
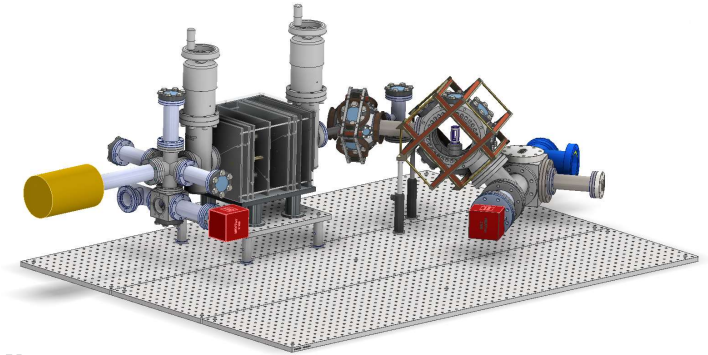
CHALLENGE

- sub-wavelength tweezer array
- integration with cavity



IMPLEMENTATION

- Bose–Einstein condensation of ^{174}Yb
- finalized the design of the high-finesse cavity
- developed the concept for high-resolution imaging and optical tweezers



First ultracold atoms signal

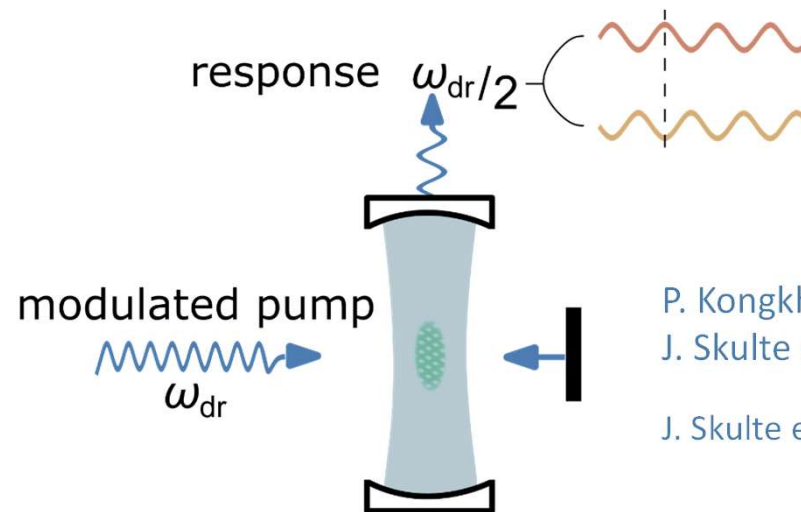


CAVITY COLD ATOM CLOUD (Hamburg)



IMPLEMENTATION:

- driven cold atom cloud in a cavity
- Investigation and realization of dissipative time crystals



P. Kongkhambut et al., Rep. Prog. Phys. 87 080502 (2024)

J. Skulte et al., Phys. Rev. A 109, 063317 (2024)

J. Skulte et al., Phys. Rev. Lett. **130**, 163603 (2023)





SCIENTIFIC OUTPUTS



PUBLICATIONS AND PRESENTATIONS

33 publications, 4 arXiv (7 PRL, 1 PRX Quantum, 1 Nature Physics, 1 Nature)

12 Invited talks, 5 contributed talks

1 patent (US20260094042A1)



NUMBER OF BACHELOR, MASTER AND PhD THESES

3 master theses,

6 PhD theses



IMPACT (RRI aspects)



GENDER:

- female leader
- organization of round table on gender balance



OPEN SCIENCE:

- all publication on arXiv,
- submission to open accessible journals



SCIENCE EDUCATION:

- lecture at Bežigrad high-school, Ljubljana
- organization and lecturing at 6 schools for master/PhD student



PUBLIC ENGAGEMENT:

- [TEDx talk](#)
- interview with female coordinators
- Science on the street event
- interviews and podcast in public media



ETHICS:

- applying fundamental ethical principles and legislation



QUANTUM FLAGSHIP: QCN member (Slovenian representative)

MEETINGS

4 consortium meetings (2022, 2023, 2024, 2025)

QuSiED “Next generation” symposium
ICFO 2024

Invited speakers: young/future leaders



Quantum simulation with engineered dissipation

Obergurgl 2025

Final conference

