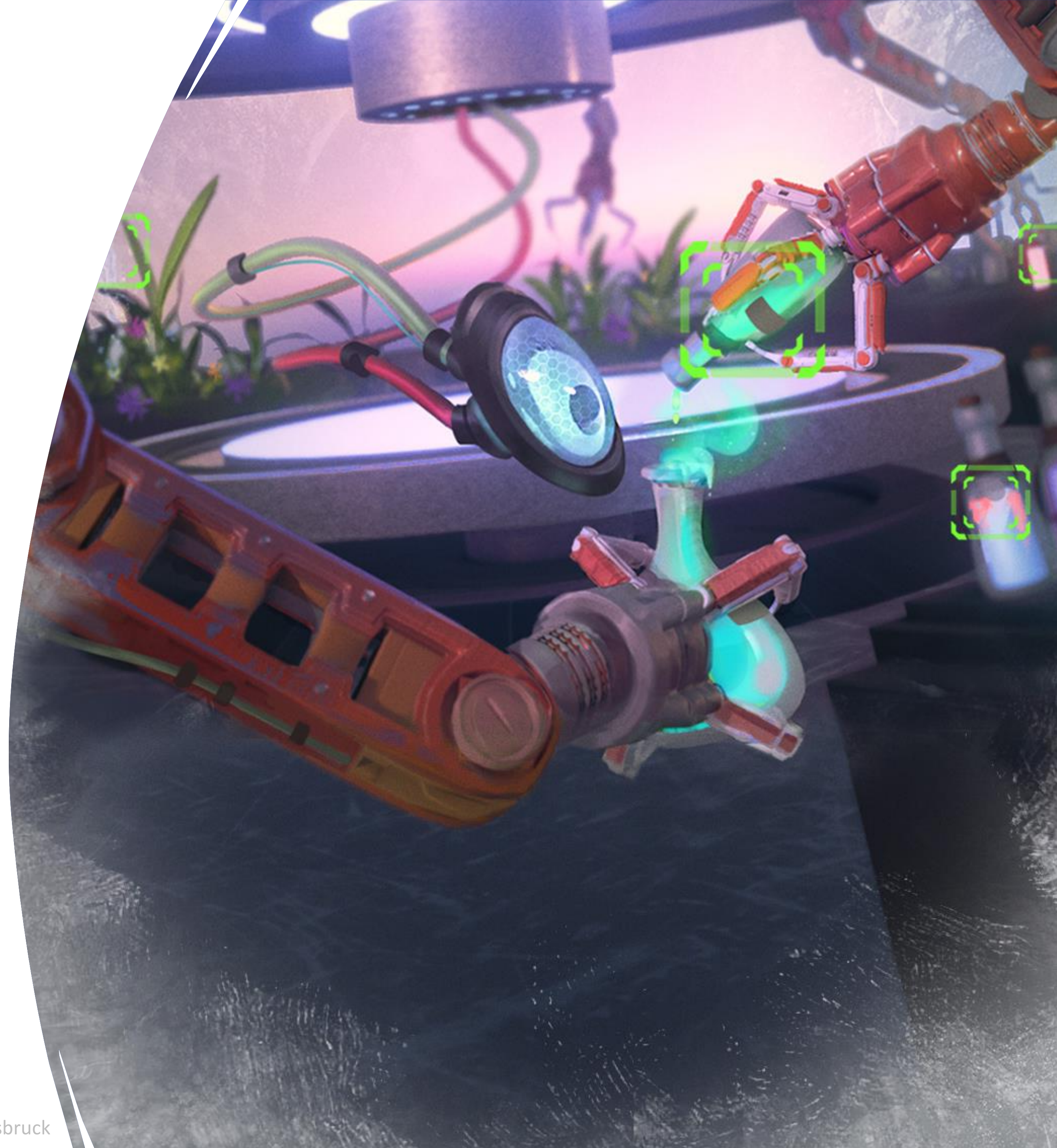
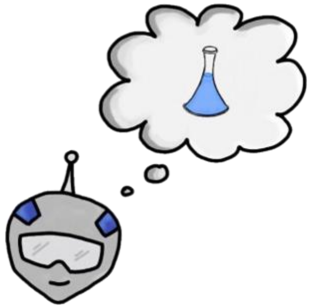
Measurement-based Quantum Computation, Learning and Agency

AG Briegel

Hendrik Poulsen Nautrup

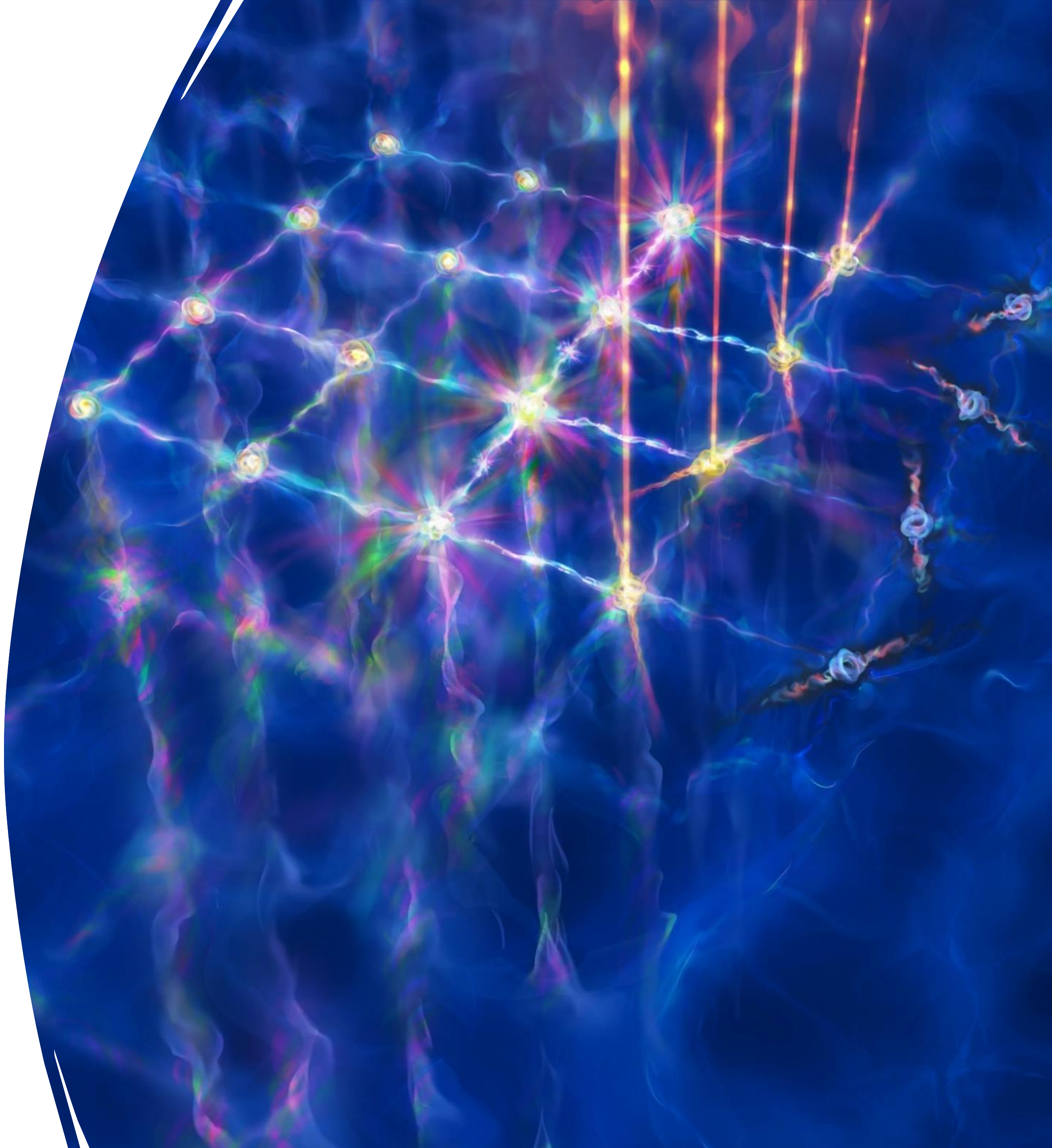
08.01.24





Explainable AI	Learning from learning agents
Automated scientific discovery	Machine Learning for Science
Quantum Machine Learning	Machine Learning in the Quantum Domain
Measurement-based Quantum Computation	Quantum Computation and Information

Measurement-based Quantum Computation

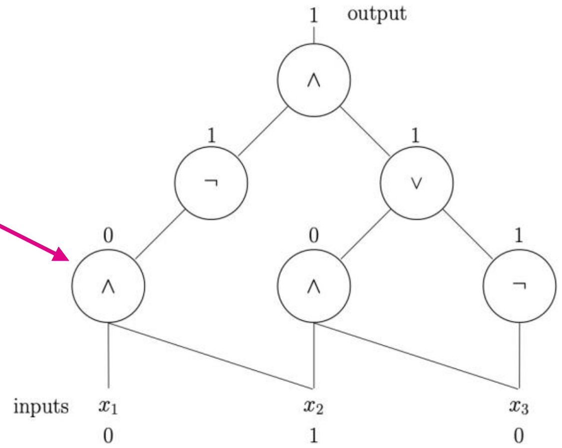


Nielsen and Chuang (2000), Quantum Computation and Quantum Information
HPN et al (2023), arXiv:2312.13185

Quantum Computation

Boolean circuit

Gate

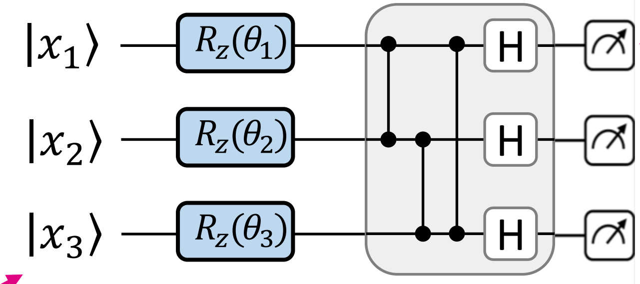


Bit information carrier

Quantum circuit

Gate

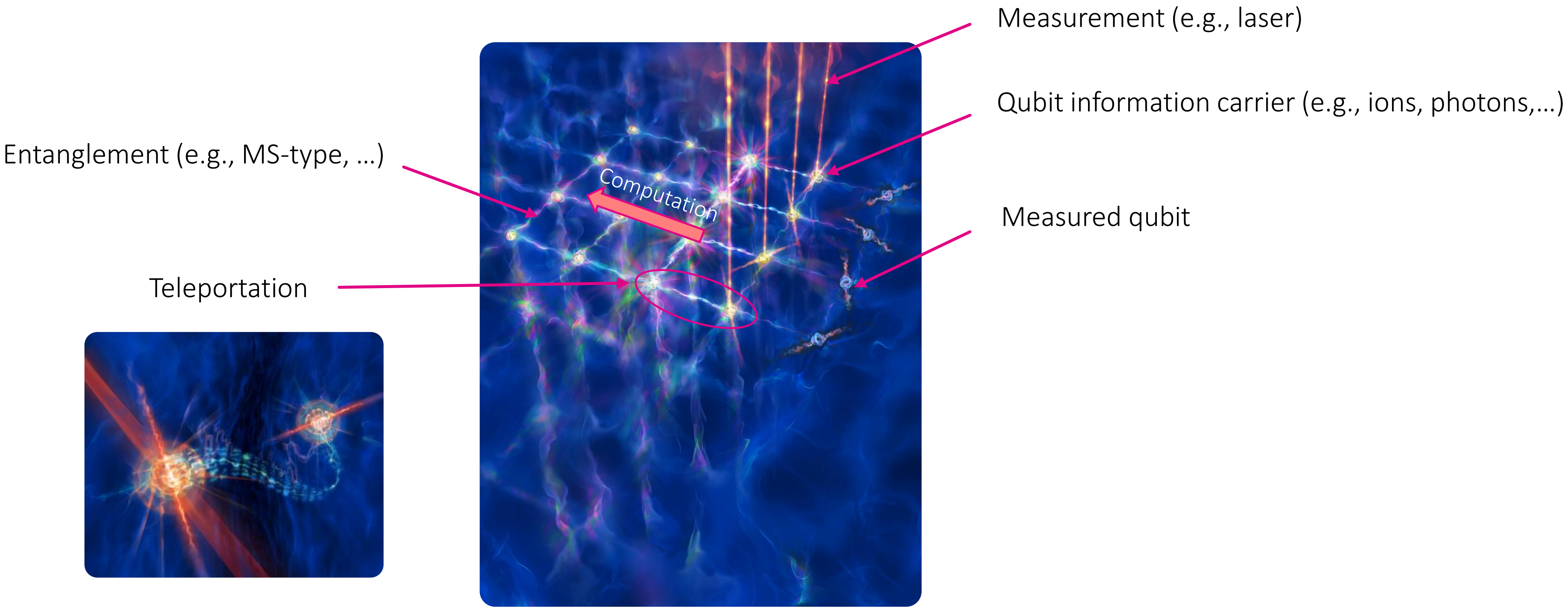
Output measurement



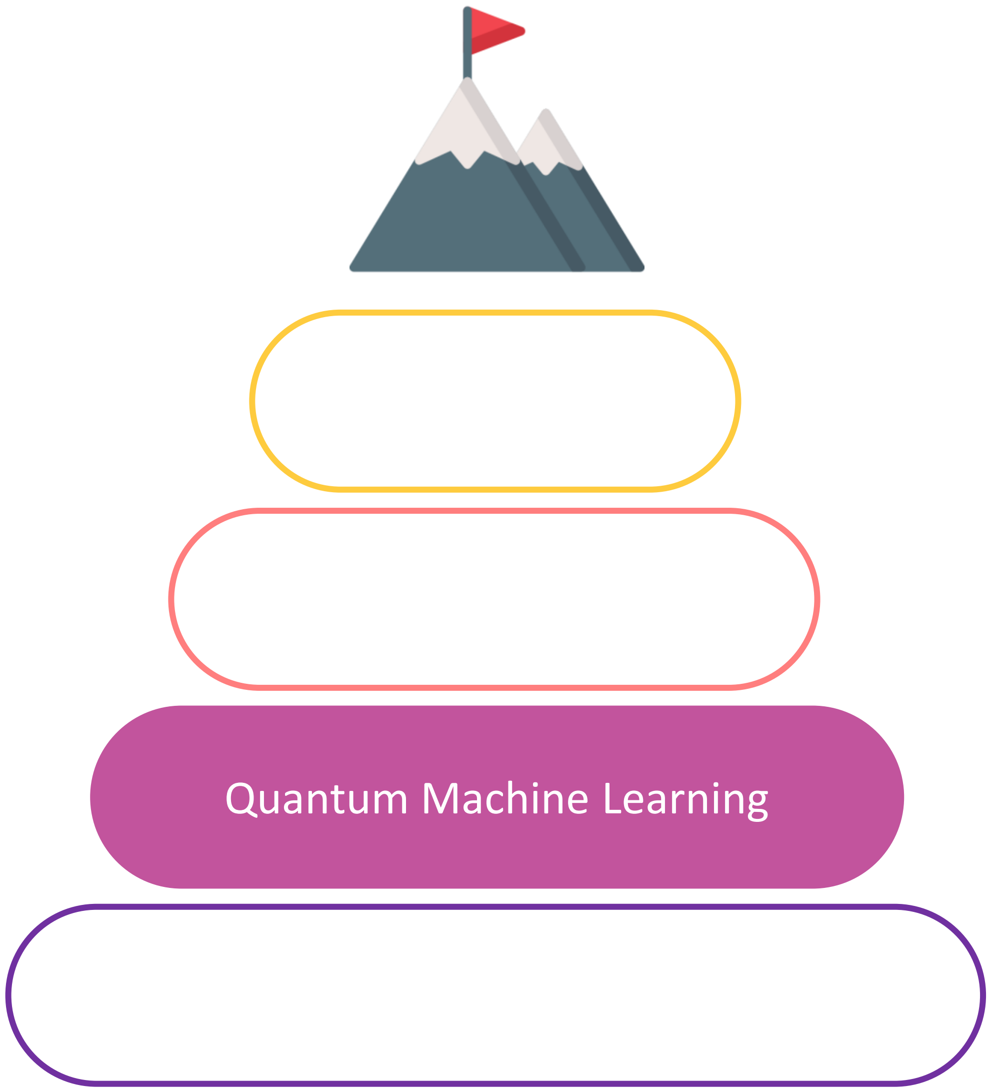
QuBit information carrier

Nielsen and Chuang (2000), Quantum Computation and Quantum Information

Measurement-based Quantum Computation

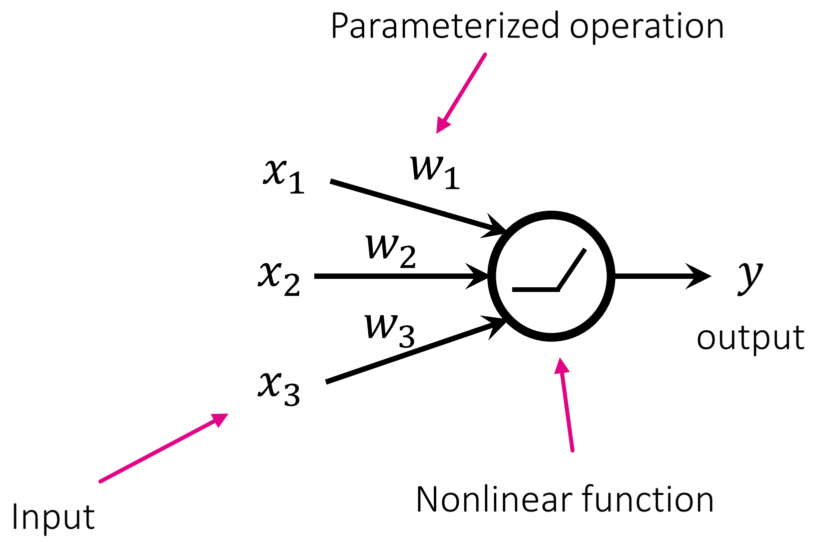


HPN et al (2023), arXiv:2312.13185

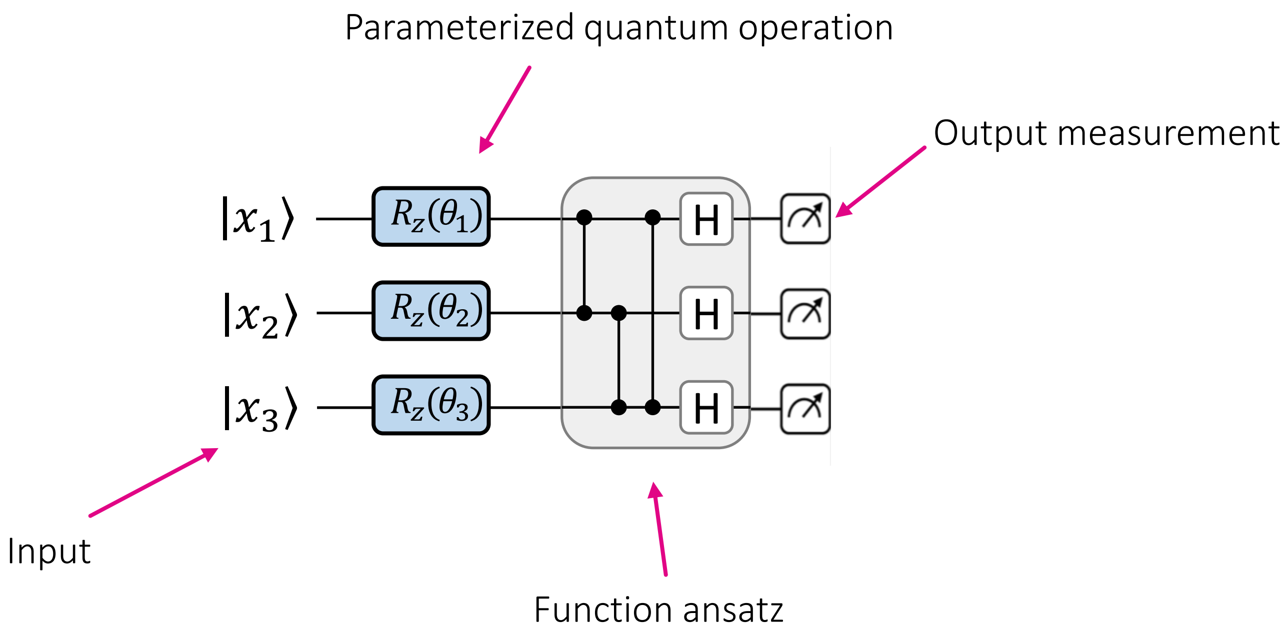

Quantum Machine Learning

Quantum Machine Learning

Classical Neural Network

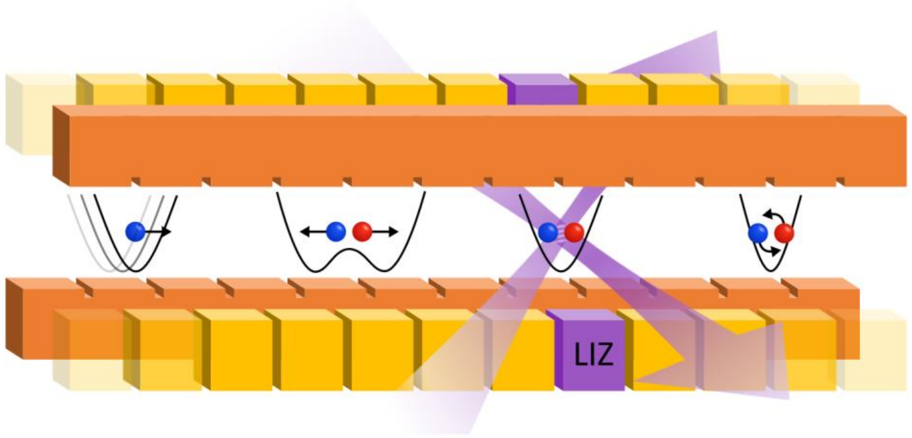


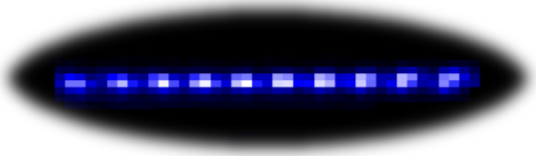
Quantum Neural Network

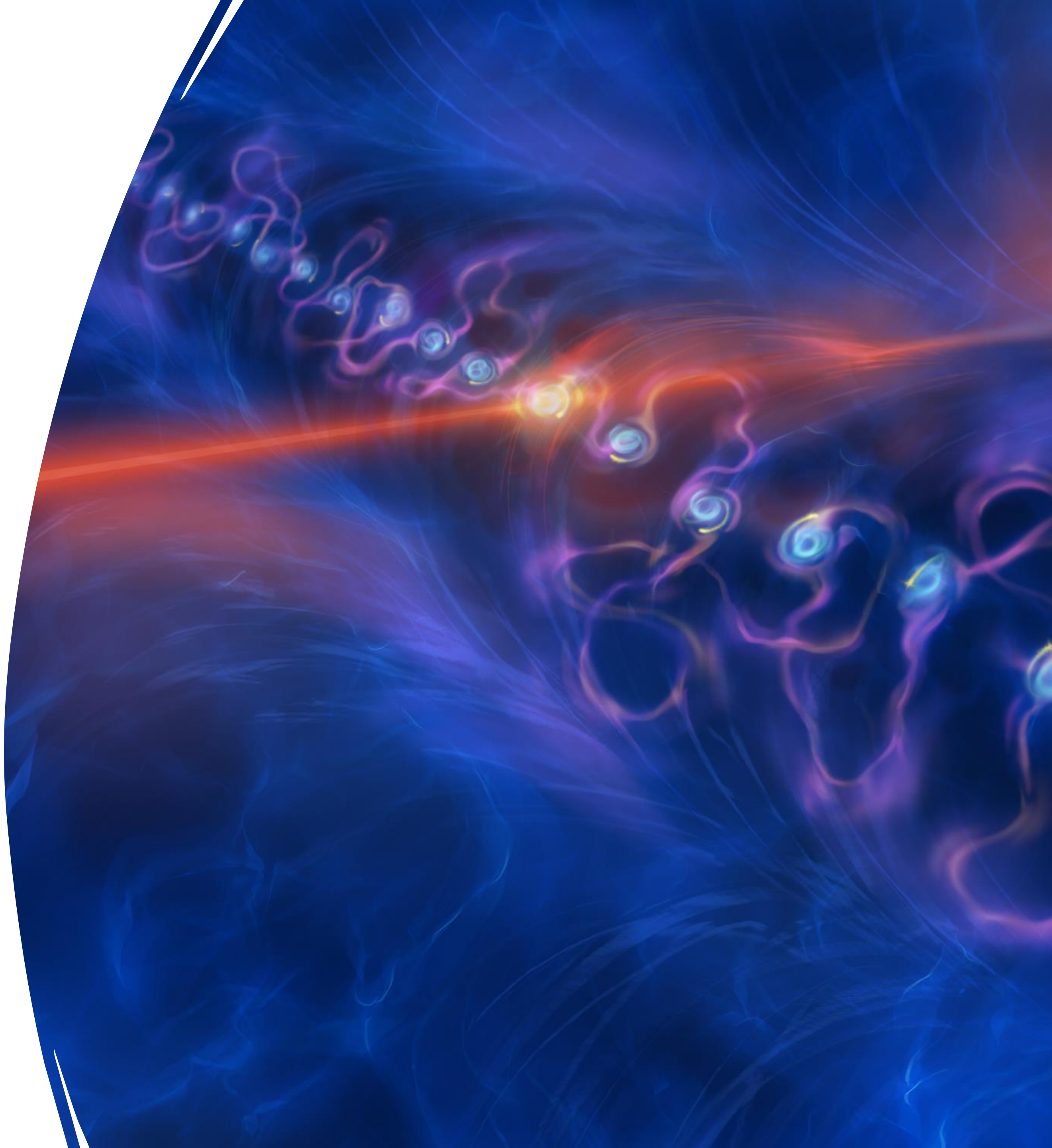


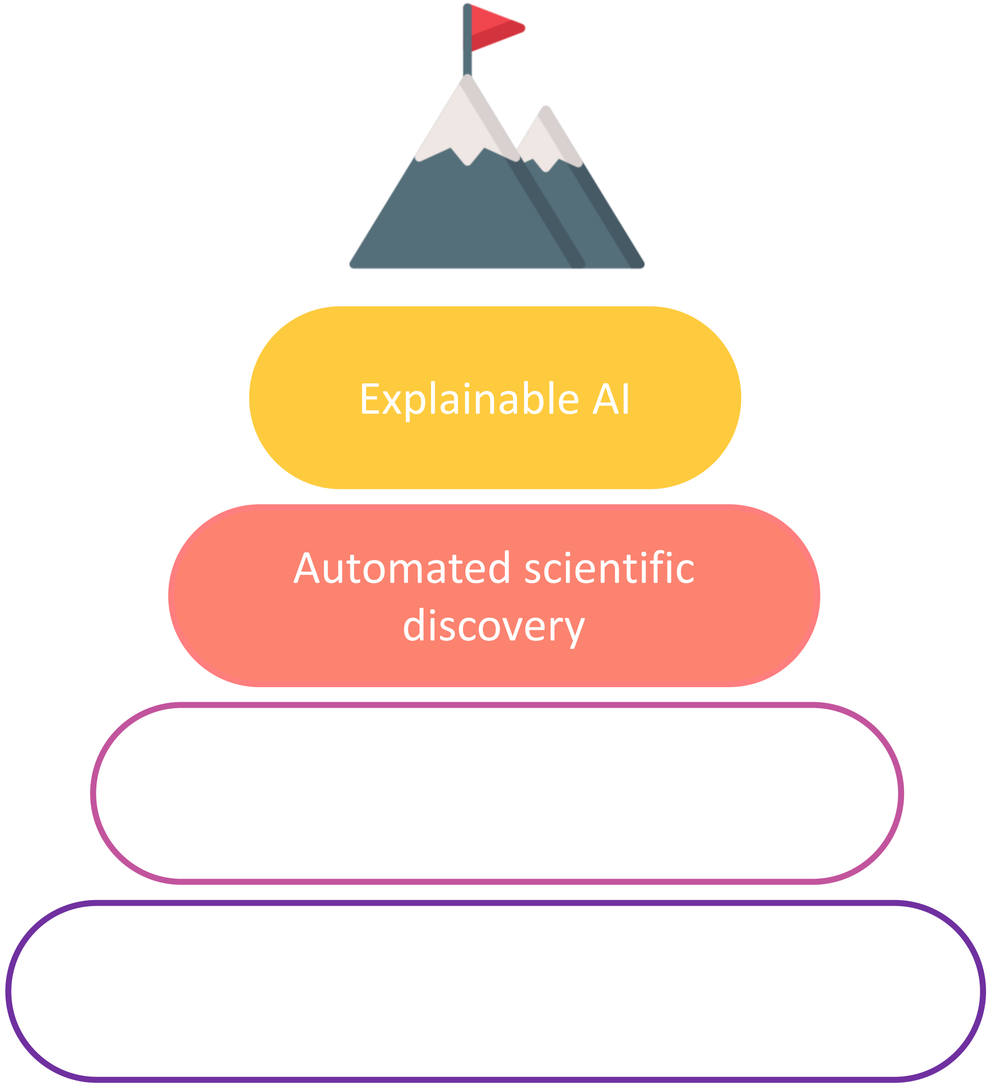
HPN et al (2023), arXiv:2312.13185

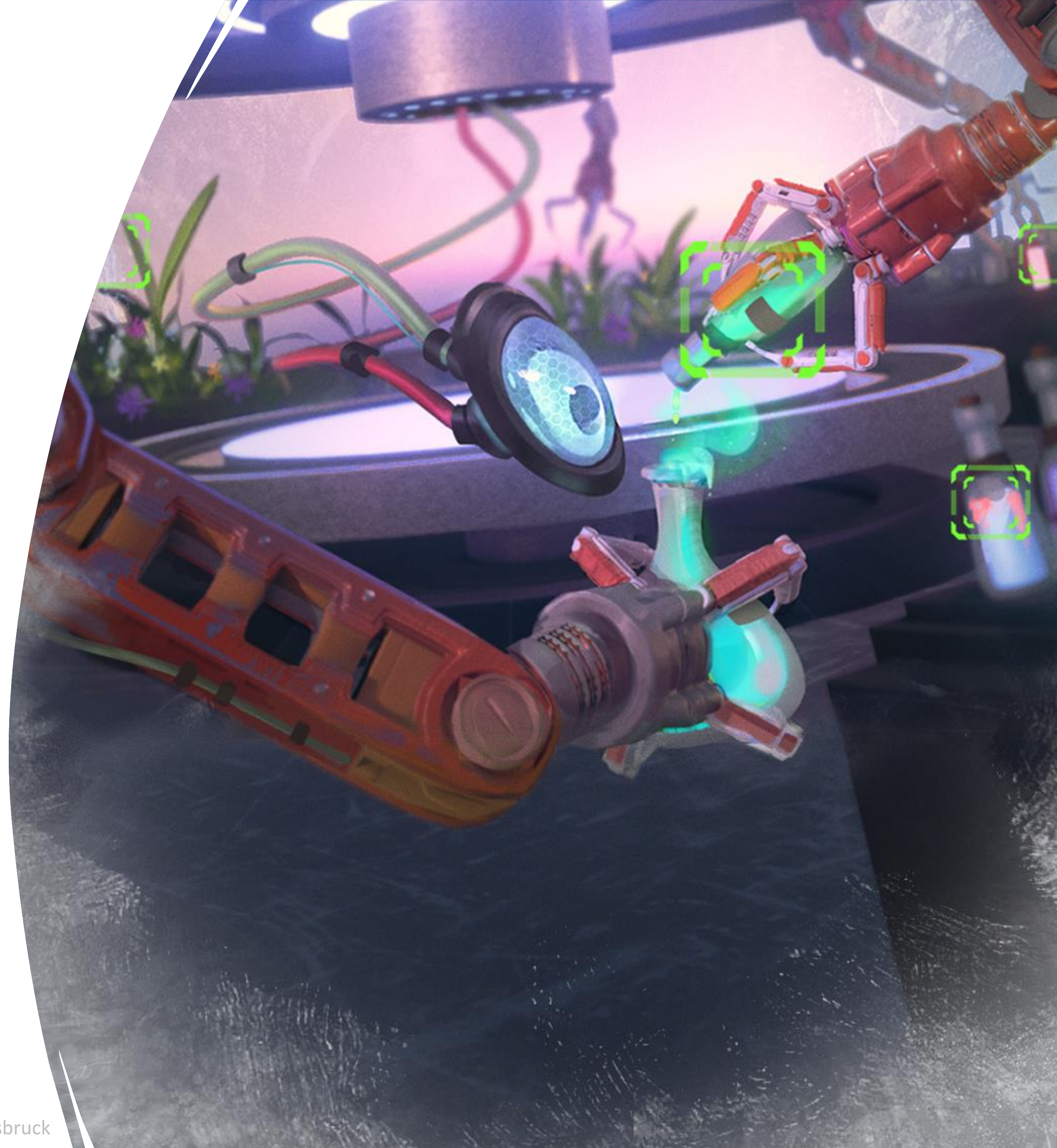
Ion Trap Quantum Computers



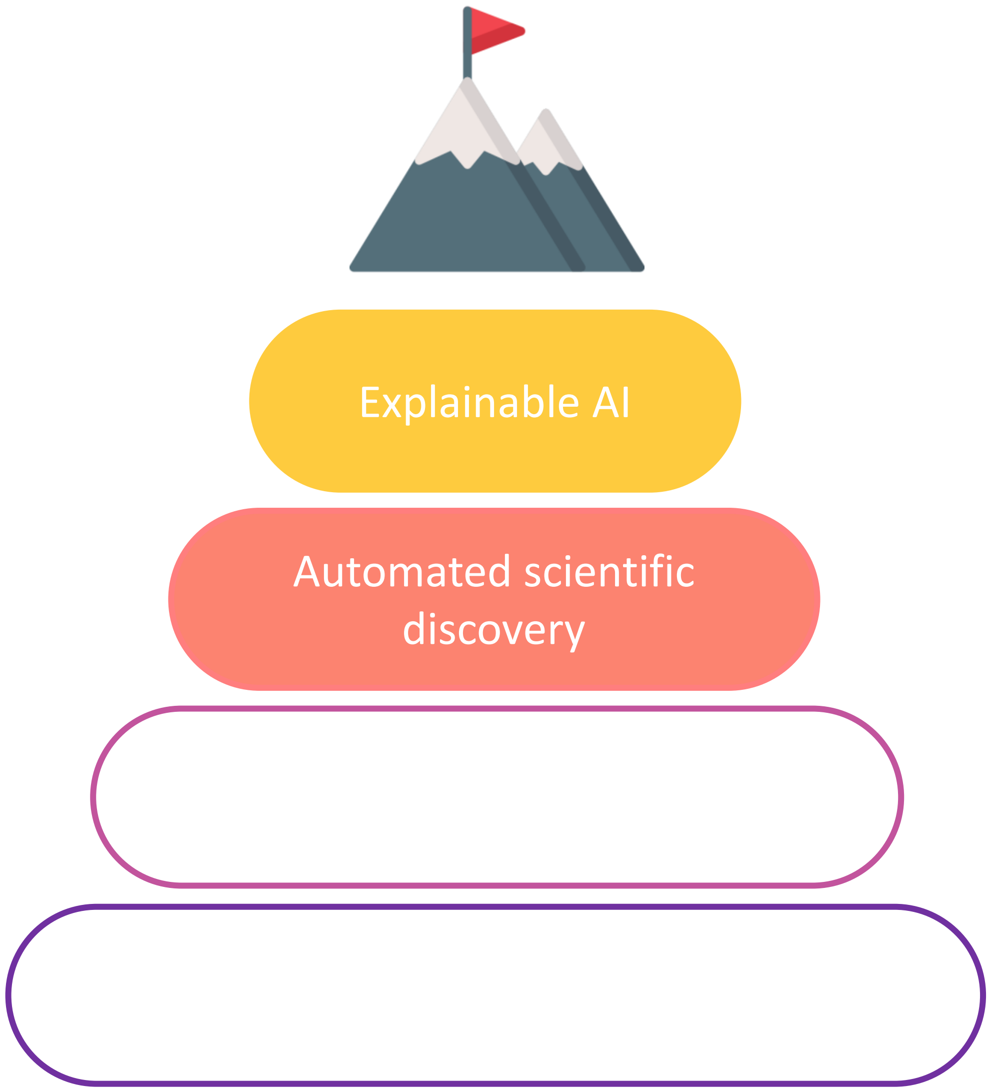




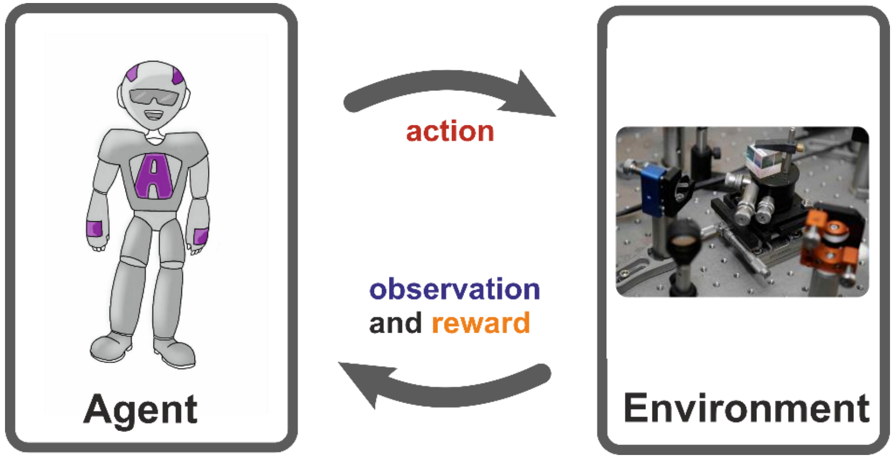




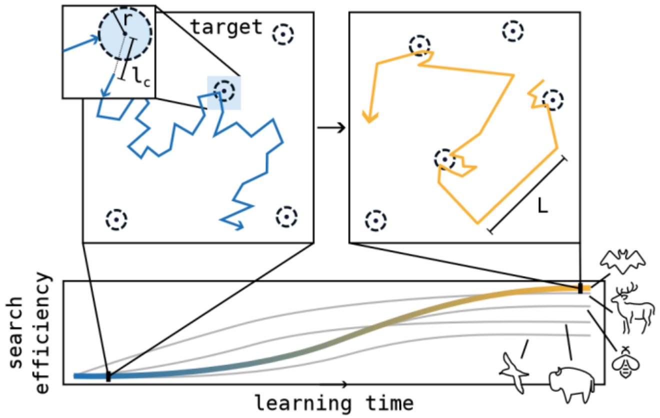
Ilustr. Mchele Esposito



Reinforcement Learning



Behavioral Biology



Explainable AI

Automated scientific discovery

Quantum Machine Learning

Measurement-based Quantum Computation

Come talk to us!

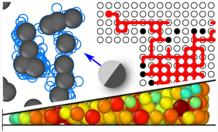
Theoretische Bio-Nano Physik

Prof. Thomas Franosch, Michele Caraglio

8. Jänner, 2024

Vorstellung Arbeitsgruppen

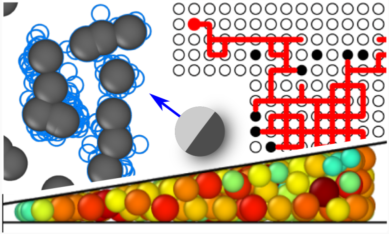
Institut für Theoretische Physik
Universität Innsbruck (UIBK)



Soft matter / Statistical Physics

Active particles

Complex transport



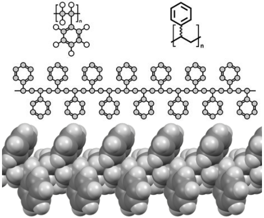
Glass transition

Polymer Physics

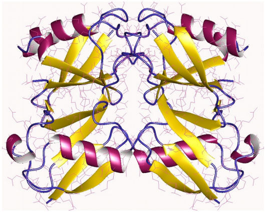
Proposal

Polymers

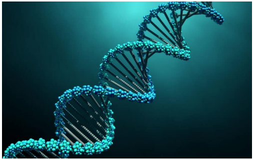
Polysterene

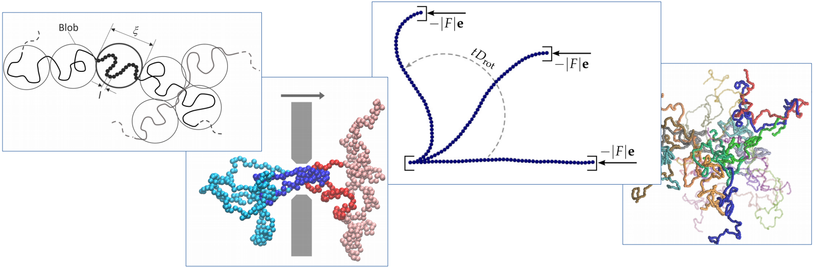


Proteins



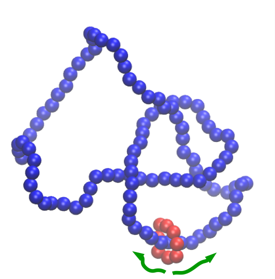
DNA and RNA





Polymers: Bachelor Proposal

Goal: Investigate the sliding dynamics of rings along polymeric chains whith non-trivial topology.



Learning objectives:

- Learn how to simulate polymeric systems through computer simulations;
- Learn basic notions of polymer topology (knots and links);
- Analyze the motion of the ring through the basic concepts of stochastic processes.

Active particles

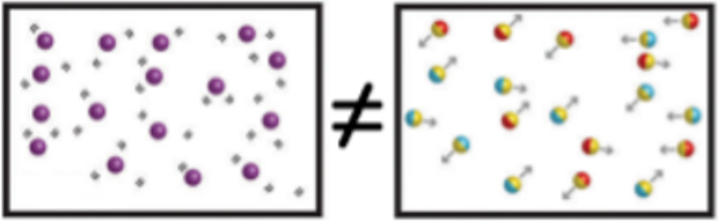
E. Coli

many E. Coli

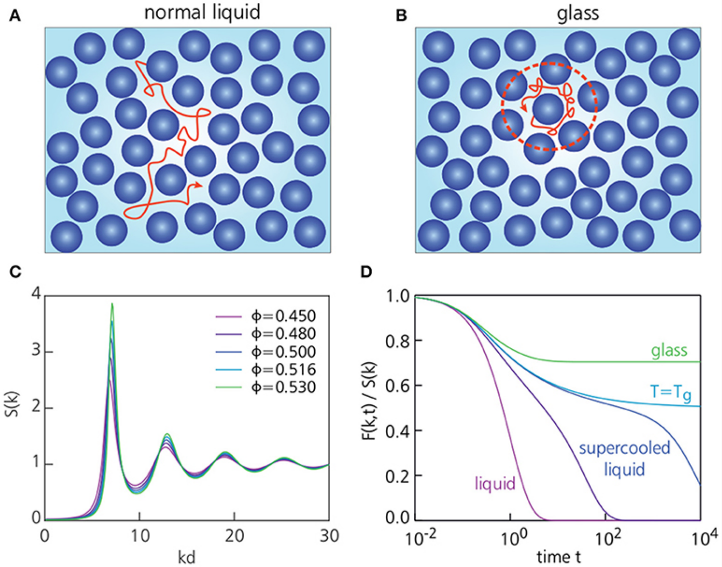
Flock of birds

schol of fishes

standard Brownian particles ≠ active Brownian particles

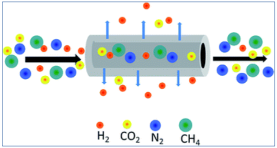


Glass Transition

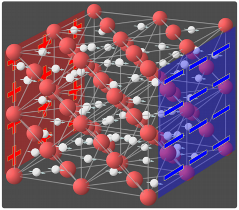


Complex transport

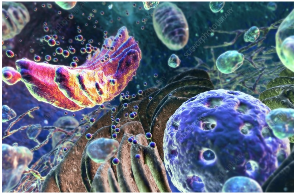
Molecular sieve



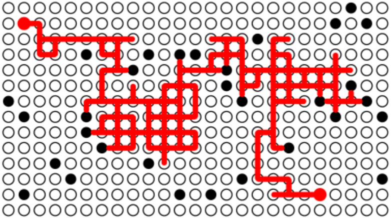
Ion-conductor



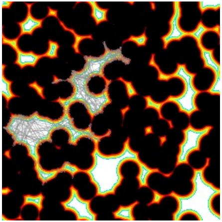
Interior of cells



Lattice Lorentz Gas

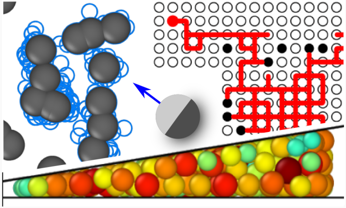


Lorentz Model



Potential Master theses available in various topics

- Glass transition
- Active particles
- Complex transport

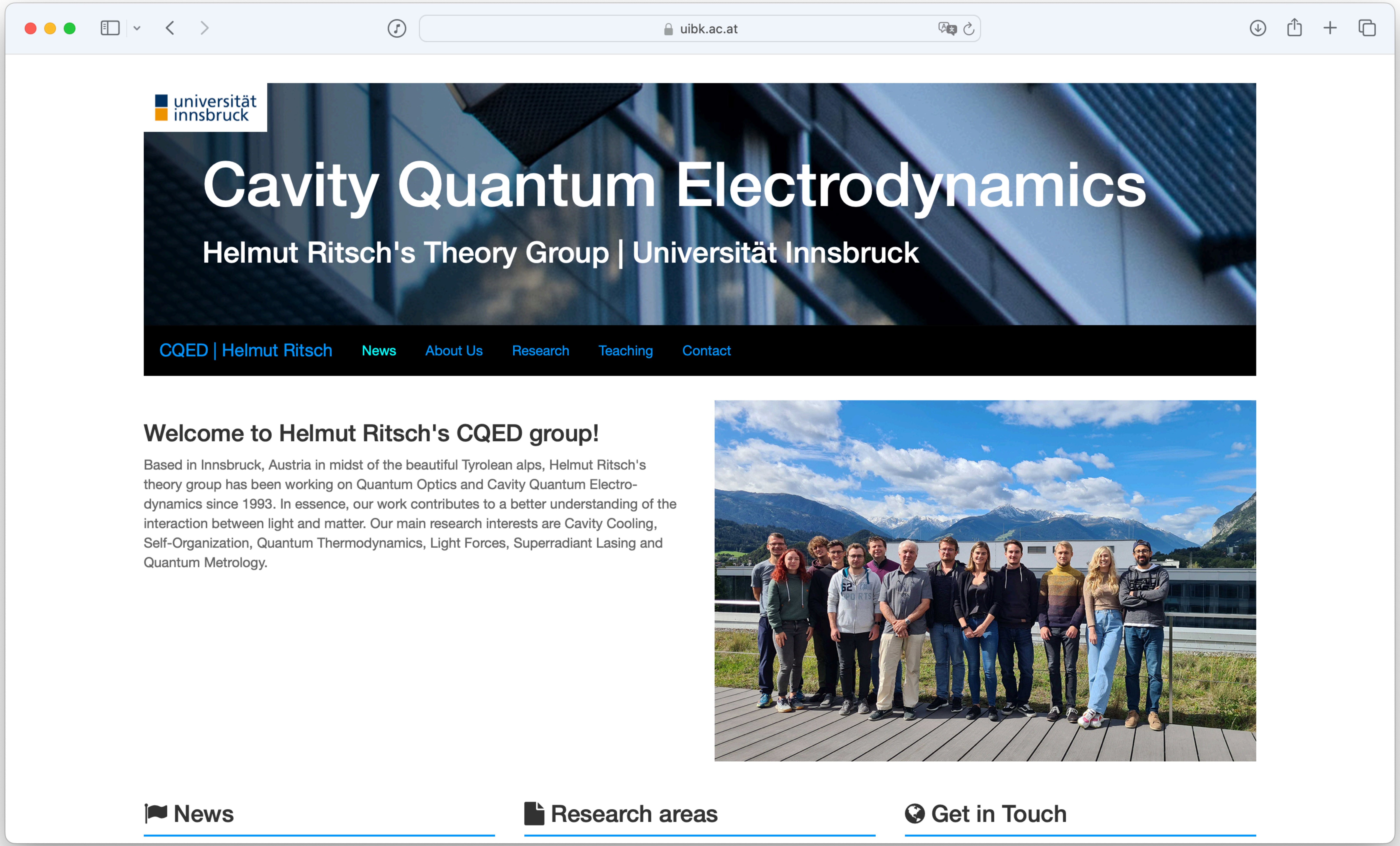


If you are interested, please just approach us!

Thank you for your attention!

Quantum Optics & Ultracold Gases

Prof. Helmut Ritsch
Dr. Farokh Mivehvar
Dr. Laurin Ostermann



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Google "Ritsch Group"

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universität innsbruck

Cavity Quantum Electrodynamics

Helmut Ritsch's Theory Group | Universität Innsbruck

CQED | Helmut Ritsch   News   About Us   Research   Teaching   Contact

Research

This page details our research efforts and interests. Below you will find a selection of topics we are currently working on. For a list of publications please see the links.

Cavity cooling | Self-organization | Quantum engines | Light forces | Superradiant lasing | Metrology | QuantumOptics.jl

General research statement

Our research covers the fields of theoretical quantum optics and ultra cold gas physics with strong connections to quantum information theory, foundations of quantum physics and quantum theory of condensed matter systems. We focus on full quantum descriptions of matter and light waves, which are strongly coupled by momentum exchange. Our aim is an effective theoretical description of real physical systems in a close connection with experiments, where genuine quantum phenomena as quantum phase transitions, entanglement and macroscopic super positions can be studied in a well-controlled and understood environment.

Publications

For an (almost) complete list of publications that have emerged from our research, please visit

- catalog in the arXiv
- page on Google Scholar
- theses collection

or co[illegible]y.

Light forces in high-Q cavities

Cavity cooling

- *Ultracold Atoms in Resonator-Generated Optical Lattices*, C. Maschler (Download PDF)
- *Interaction between optically trapped particles due to optomechanical coupling*, J. Asboth (Download PDF)
- *Cold atoms in optical resonators*, M. Gangl (Download PDF)

Diploma/Master theses

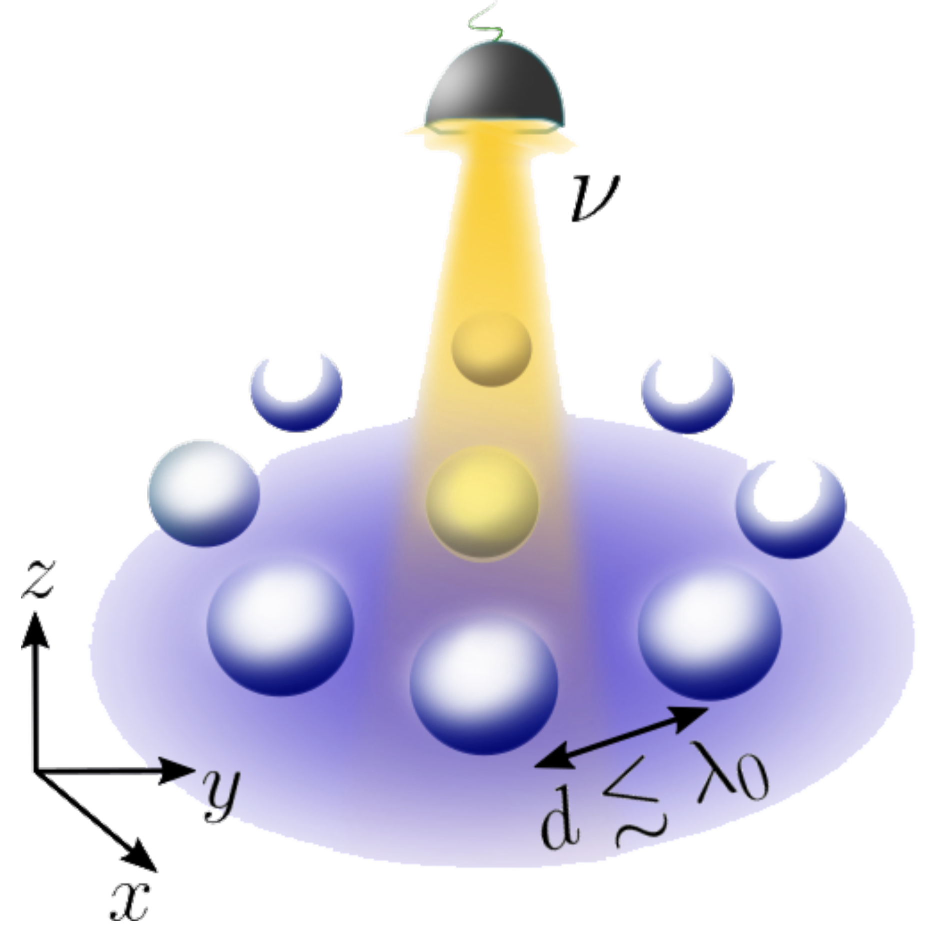
- *Symbolic Indices and Summations in QuantumCumulants.jl*, J. Moser (Download PDF)
- *Simulating a superradiant laser based on a thermal atomic beam*, M. Fasser (Download PDF)
- *Exciton Dynamics in Coupled Nano-Rings of Dipolar Quantum Emitters*, V. Scheil (Download PDF)
- *A study of the origin of a quantum advantage in simulated annealing*, E. Starchl (Download PDF)
- *Dipole-Coupled Nano-Ring(s) of Quantum Emitters*, J. Cremer (Download PDF)
- *Superradiance in Atomic Arrays with a V-Type Level Structure*, R. Holzinger (Download PDF)
- *Superradiant Cooling, Trapping and Lasing of Dipole-Interacting Clock Atoms*, C. Hotter (Download PDF)
- *Tomography of time-bin entangled photons from a quantum dot*, P. Aumann (Download PDF)
- *Polarizable particles in cavity QED generated time dependent potentials*, T. Hinkel (Download PDF)
- *Adaptive Dynamics of Scatterers in Multi-Frequency Light Fields in Optical Resonators*, V. Torggler (Download PDF)
- *Exploiting Collective Effects in a System of Interacting Quantum Emitters*, D. Plankensteiner (Download PDF)
- *Self-Ordering and Collective Dynamics of transversely illuminated Point-Scatterers in a 1D Trap*, D. Holzmann (Download PDF)
- *Nonlinear Optomechanical Dynamics of a Quantum Particle in a Single-Mode Cavity*, D. Winterauer (Download PDF)
- *Superradiant clock laser on an optical lattice*, T. Maier (Download PDF)
- *Scattering approach to multicolour light forces and self-ordering of polarizable particles*, S. Ostermann (Download PDF)
- *Simulating open quantum systems with high photon numbers in coherent bases*, S. Krämer (Download PDF)
- *Two interacting atoms in a quantum optical potentia*, K. Renz (Download PDF)
- *Cavity induced atom cooling and trapping*, G. Hechenblaikner (Download PDF)

Bachelor theses

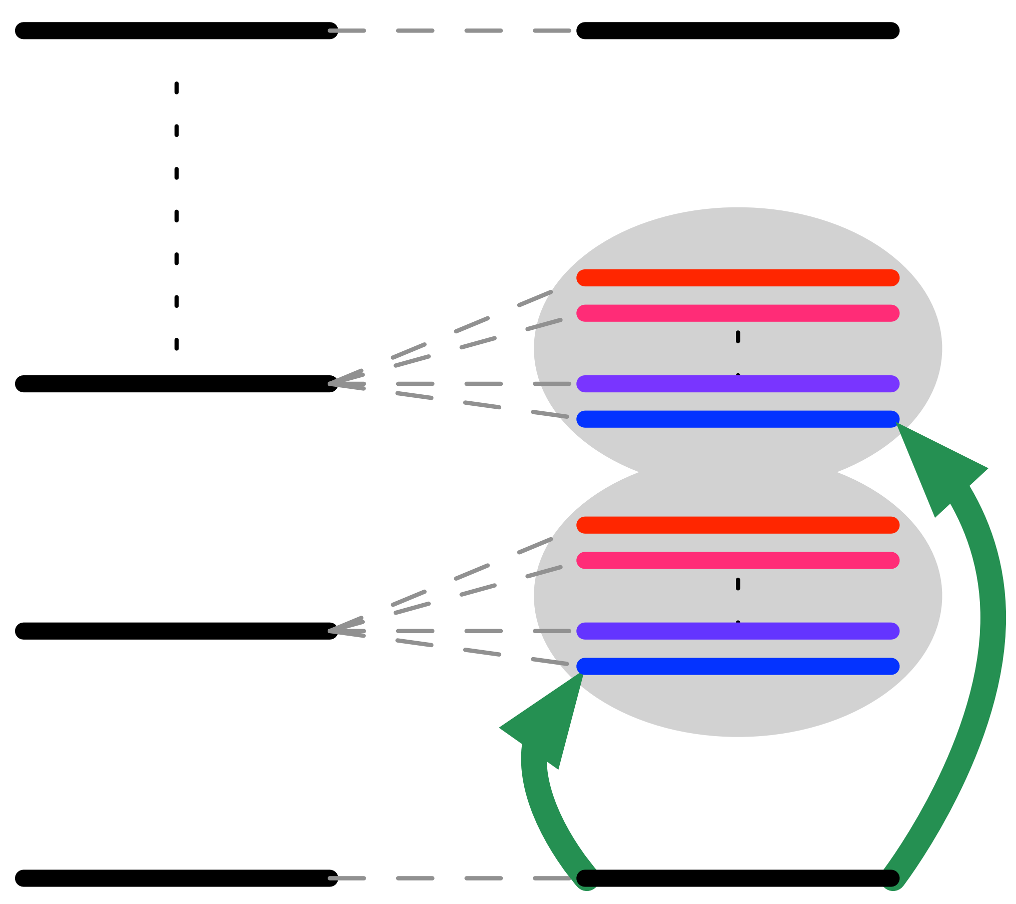
- *A beam splitter for interacting quantum particles*, M. Schöpf (Download PDF)
- *The Three-Level Laser as a Quantum Heat Engine*, M. Dannemüller (Download PDF)
- *Sub- and superradiance in different geometries of interacting two level systems*, N. Karner (Download PDF)
- *Photonenstatistik von kooperativer Emission gekoppelter Dipole*, P. Zwetkoff (Download PDF)
- *A Superradiant Laser*, M. Fasser (Download PDF)
- *Cavity QED with Cold Particles*, B. Gstrein (Download PDF)
- *2D Solitons in QuantumOptics.jl*, B. Ertel (Download PDF)
- *Prime Factorization using a System of Spins with Controlled Coupling*, V. Zeni (Download PDF)
- *Spontaneous Emission and Superradiance*, A. Kruckenhauser (Download PDF)

Dipole-Dipole Interaction

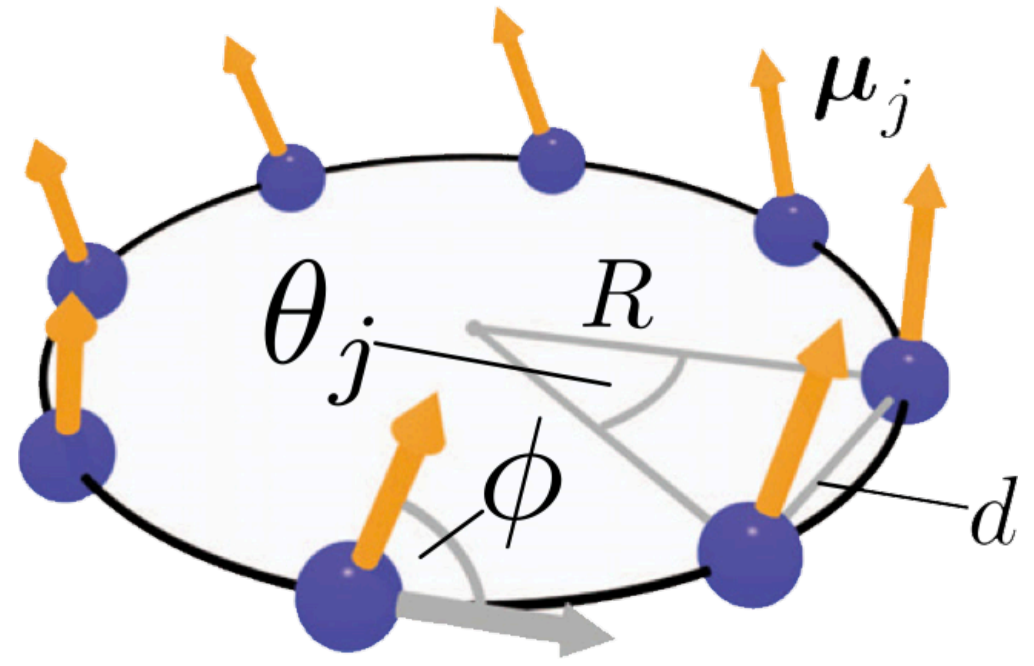
Nanoscale Laser



State Preparation

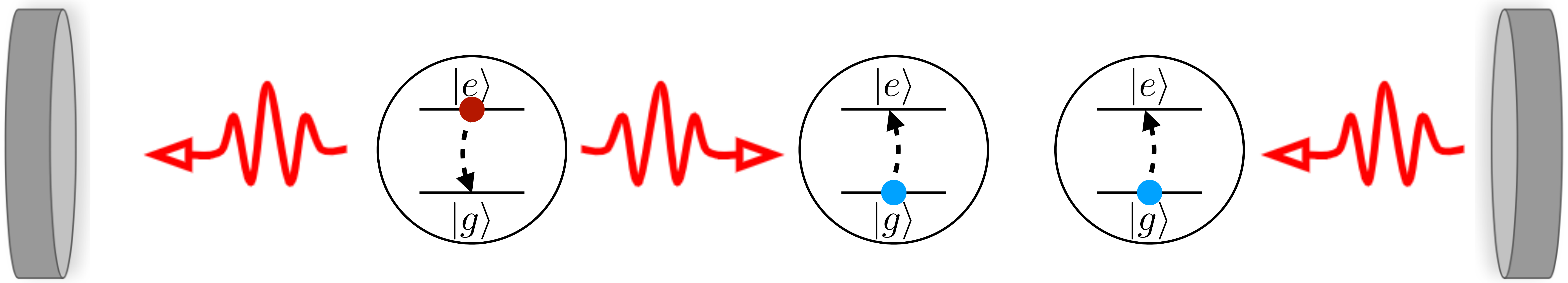


Energy Transfer



Light-Matter Interaction inside Cavities

- Many atoms interacting strongly with electromagnetic fields inside a cavity:

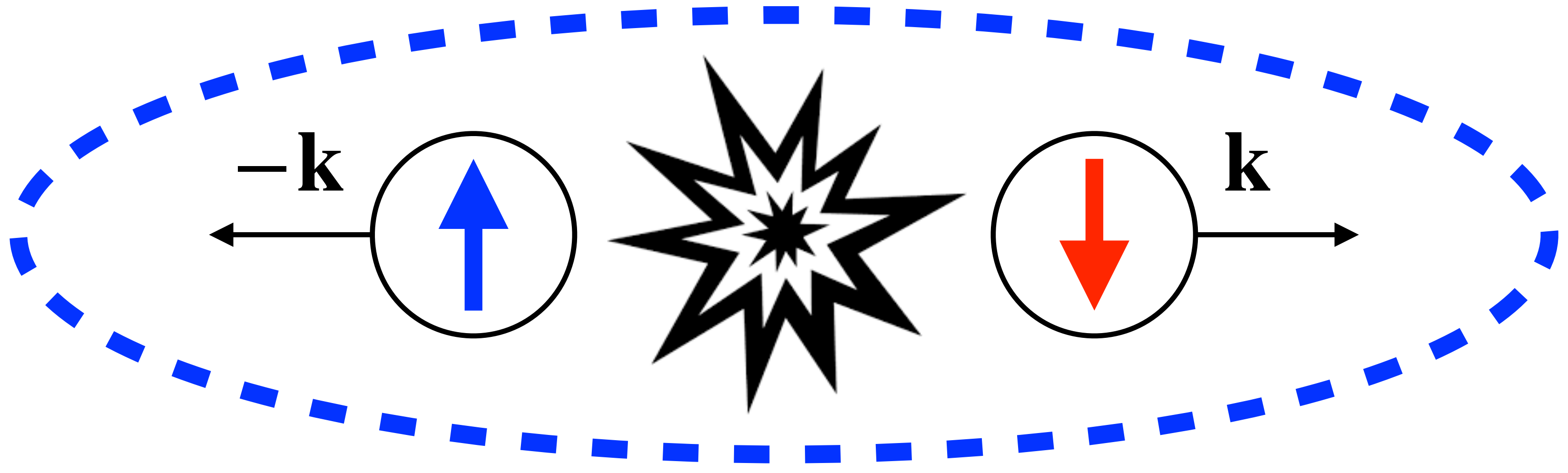


photon-induced long-range interactions between atoms

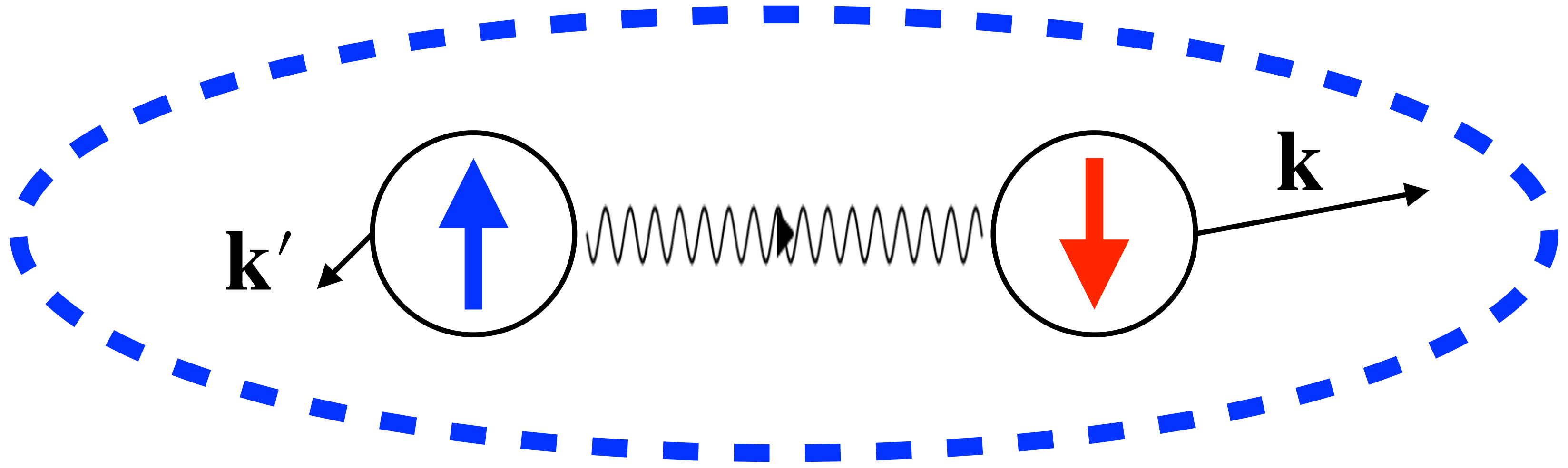
Project 1

- Photon-induced superfluid (superconducting) pairing?

interaction/phonon-induced
Cooper pairing



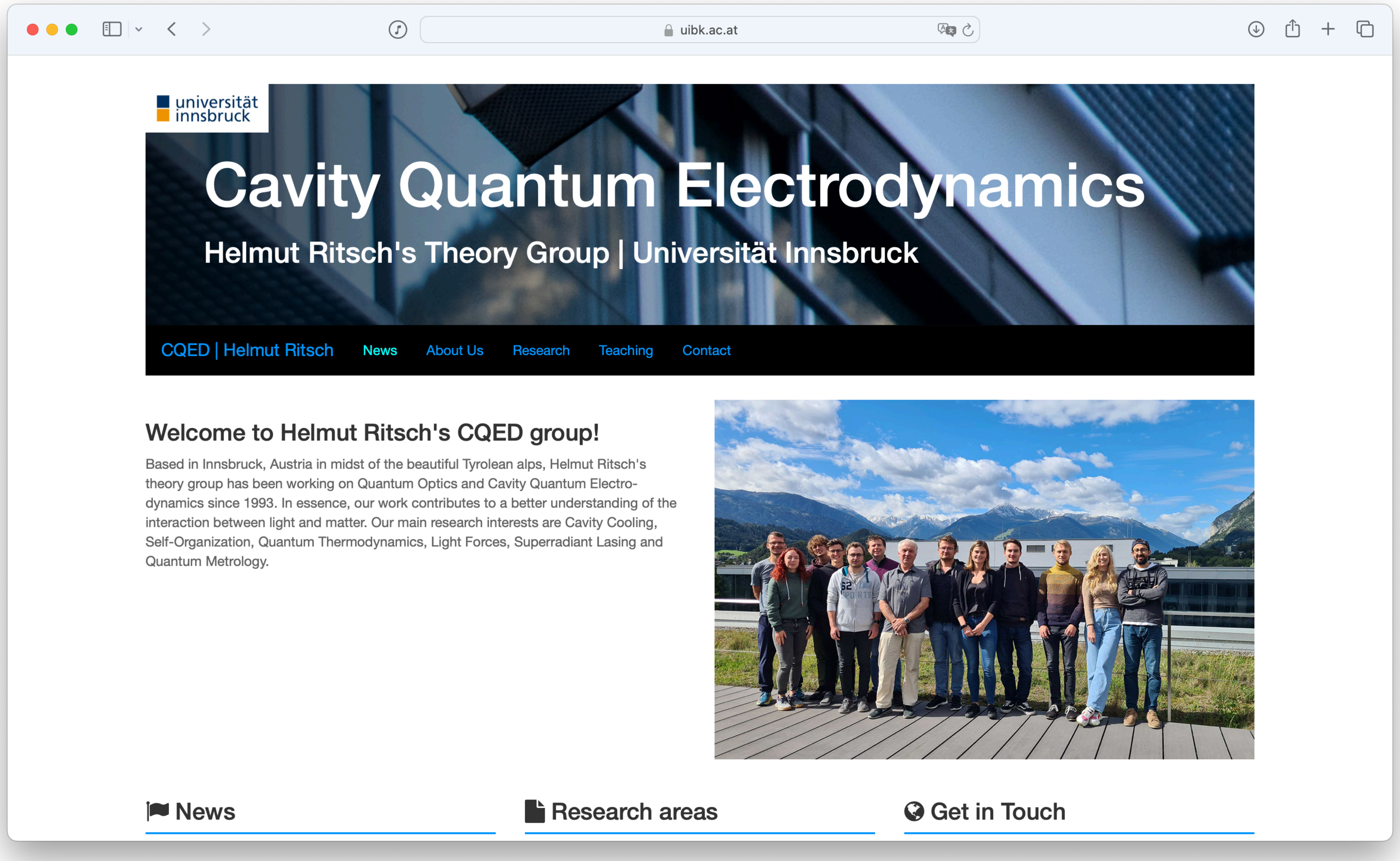
photon-induced
Cooper pairing with non-zero
CM momentum?



Project 2

- Effect of photon-induced interaction on rotating molecules?

Is it possible to align molecules rotationally with photon-induced interactions?
And, is it possible to detect the degree of the molecular alignment *non-destructively* through cavity output?



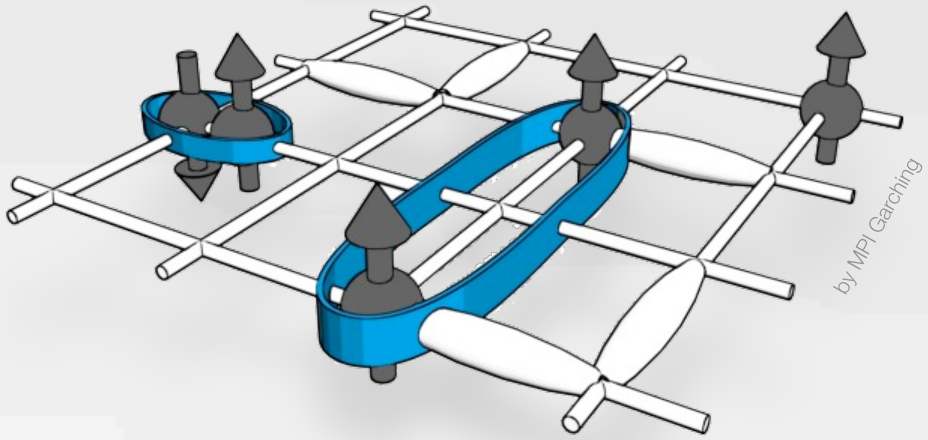
uibk.ac.at/th-physik/cqed

Google "Ritsch Group"

Theoretical condensed matter & Computational physics

Bachelor & Master thesis projects

We numerically investigate strongly correlated quantum many body systems in crystalline materials, optical traps and models, where two or more interactions are competing against each other at the same energy scale.

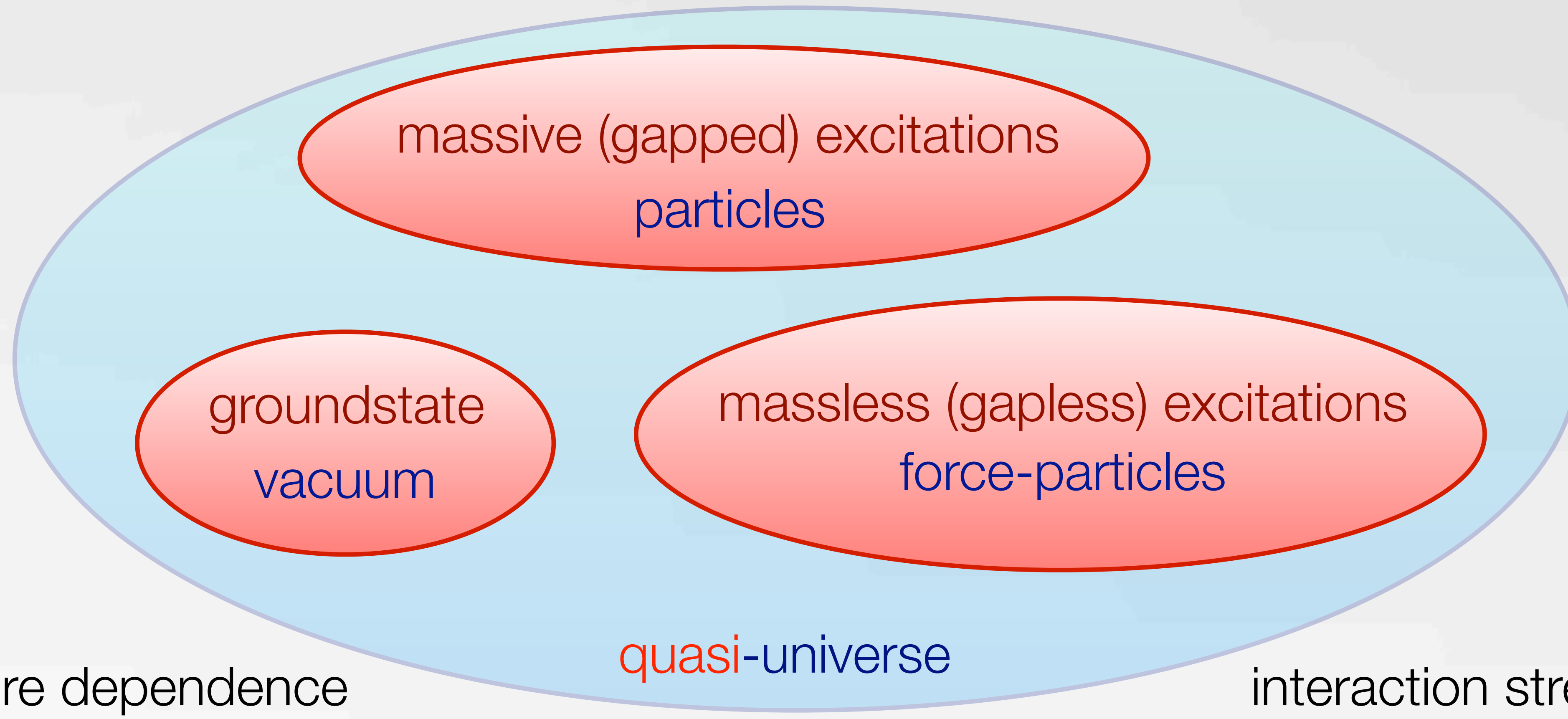


Research in this area attempts to model and simulate existing materials, as well as to predict the properties of designer materials and models.

Our challenge is to understand the fundamental, complex interplay of many degrees of freedom, which can lead to exotic states of matter.

New universes in condensed matter

- Each and every condensed matter system (crystal, model, ...) represents a universe in its own:



temperature dependence
(phase transitions)

interaction strength/range
(quantum phase transitions)

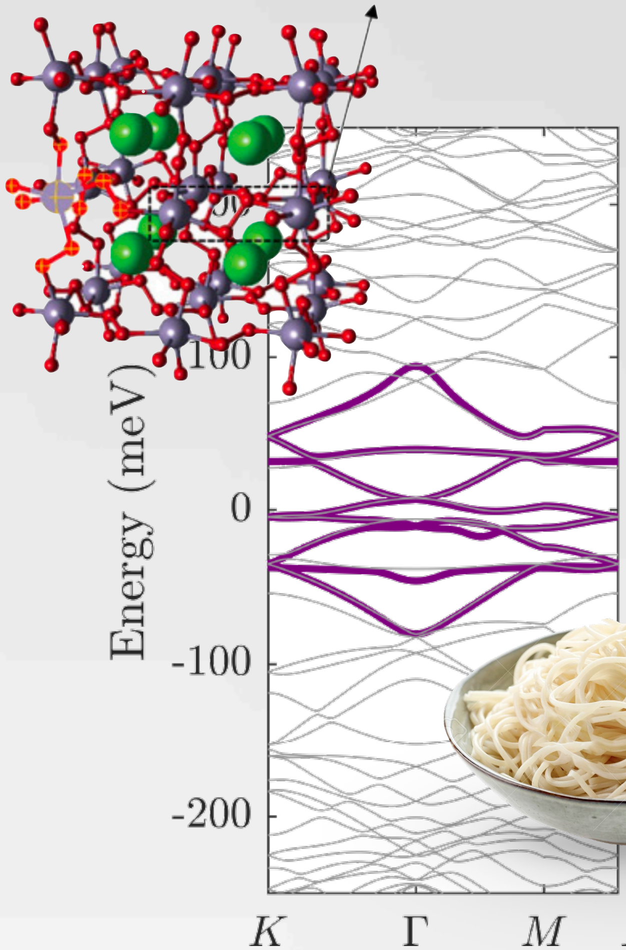
energy constraints
(lattice/bandstructure)

(emergent) quantum statistics
(fermions, bosons, anyons, ...)

- Understanding the phenomena in these systems, in particular their phase transitions allows us to learn fundamental physics and understand materials at the same time!

Materials & designer Hamiltonians

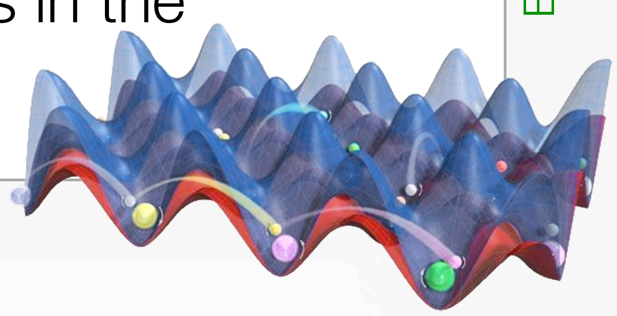
- Condensed matter physics has a long tradition of investigations being motivated by the structure and effects in crystalline materials.
- The phenomenology can be captured by simplified models.
- Yet often, even the simplified models cannot be solved, nor simulated efficiently.
- Solution:



Carr 2019

Designer Hamiltonian, *noun, \ di-ˈzī-nər ˌha-məl-ˈtō-nē-ən *

Def.: A simple effective Hamiltonian that captures the essential physical effects of complex materials and phenomena. The interactions in the Hamiltonian do not necessarily have a realistic analogue.

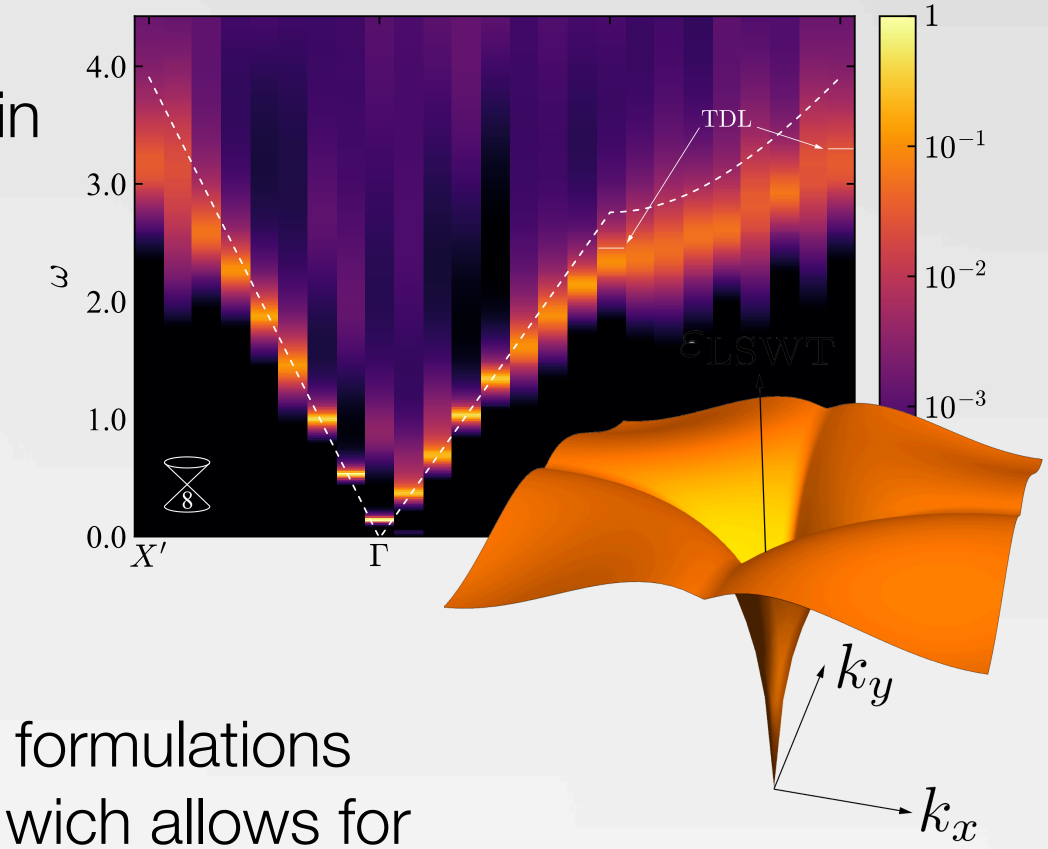


Brad Baxley, JILA

Linear spin wave theory of anisotropic long-range models

[Bachelor project]

Linear spin wave theory is a simple yet powerful approximation to extract the momentum resolved spin excitation spectrum in magnetically ordered phases.



Starting from effective descriptions of relativistic electrons, here we investigate the influence of dynamically induced anisotropic magnetic order on the spin wave spectrum.

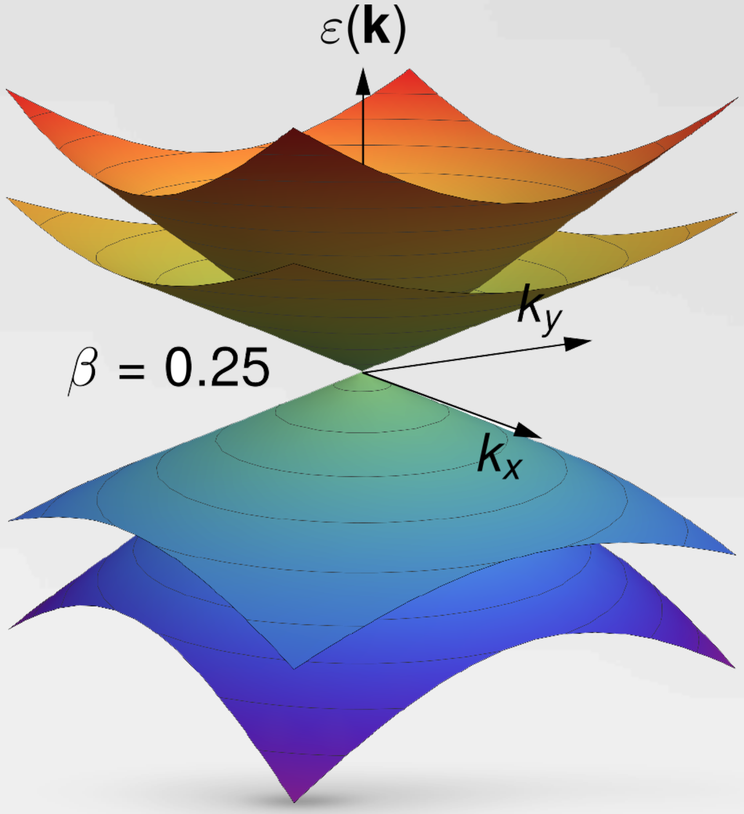
The project scrutinises a recent non-local low energy formulations of relativistic fermions in condensed matter systems, wich allows for efficient numerical simulations, yet comes with previously unknown side effects.

Lang, Läuchli, PRL 123, 137602 (2019)
Diessel, Phys.Rev. Research 5, 033038 (2023)
Song, Phys.Rev. Research 5, 033046 (2023)

Birefringent relativistic fermions

[Master project]

Imagine two relativistic electron species, with independent speed of light, strongly interacting with each other. This scenario is actually realized in several crystalline systems.

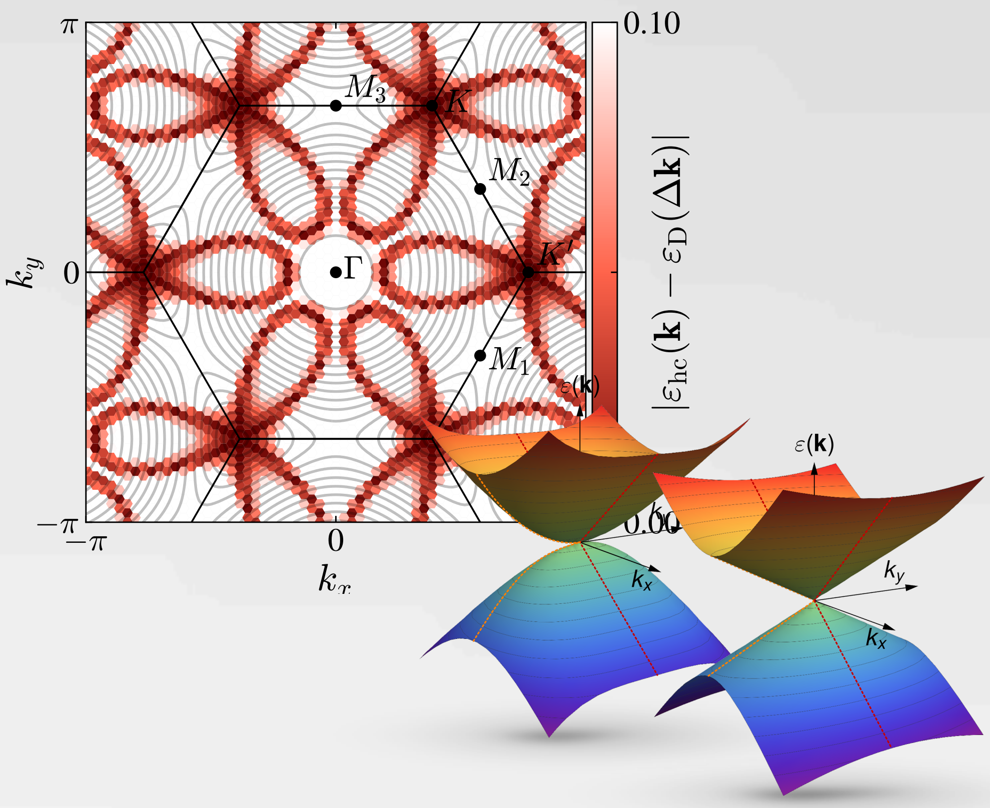


Starting from effective description, here we investigate the competition between the electron species subject to local Coulomb interactions which trigger a quantum phase transition into an insulator.

The project sets out to extract a unique fingerprint of the quantum phase transition via spectroscopy in order to (in)validate a suggested superuniversality of relativist electrons. The project combines numerical simulations, exact diagonalization and the vast theoretical background of conformal field theory.

Roy *et al.*, PRL121, 157602 (2018)
Schuler *et al.*, PRB 103, 125128 (2021)
Lang, Läuchli, PRL 123, 137602 (2019)

Locality & topology in effective fermions [Master project]



This project aims to resolve the essential differences, benefits and drawbacks of using low energy effective models when studying the quantum phase transitions of strongly interacting fermions.

Comparing local and nonlocal formulations of relativistic fermions we investigate the potential and versatility of effective Hamiltonians to overcome a gridlock in simulations of fermionic systems.

In addition we will address the role of topology, an intrinsic feature of fermions, with respect to the universality of quantum phase transitions, which has previously been sidelined due to the lack of appropriate models.

The project combines numerical simulations with comprehensive finite size scaling theory.

Lang, Läuchli, PRL 123, 137602 (2019)
Tabatbei *et al.*, *PRL* 128, 225701 (2022)
DaLiao et al., PRB 108,195112 (2023)

Contact

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ICT Gebäude, Raum 2S11
thomas.lang@uibk.ac.at

Please don’t hesitate to contact me for details!

Also, if you already have a certain project, or specific topic in the field of computational condensed matter physics in mind - your suggestions are very welcome!

Basic programming experience is required!