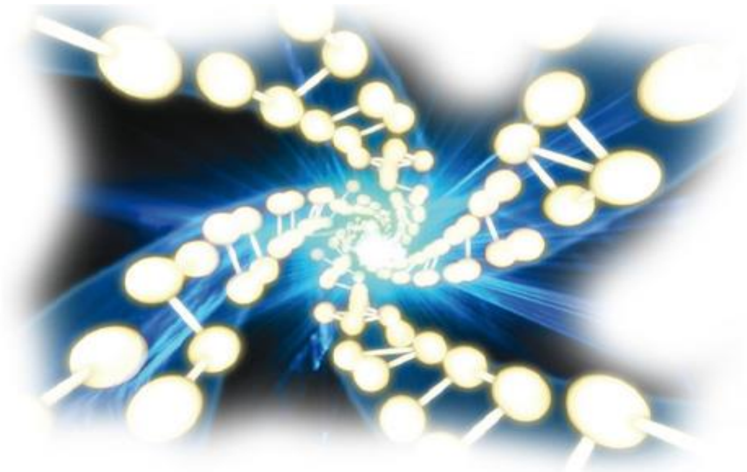


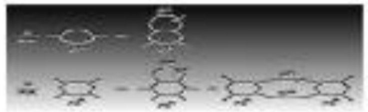
Quantum Information Science & Quantum Computation

Stefanie Barz, Irati Calafell, Borivoje Dakic, Chiara Greganti, Christopher Hilweg, Amir Moqanaki, Martin Ringbauer, Marie-Christine Röhsner, Cameron Salter, Sarah Stöckl, Max Tillmann, Rui Vasconcelos, Philip Walther

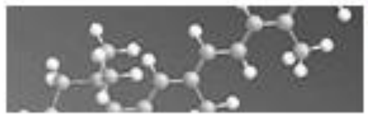
Faculty of Physics
University of Vienna
Austria

EQUAM Kick-Off
Vienna 04-11-2013

Research Groups



Andergassen Group
Quantum Many-Body Effects in Nanostructures



Arndt Group
Quantum Nanophysics and Molecular Quantum Optics

Aspelmeyer Group
Quantum Foundations and Quantum Information on the Nano- and Microscale

Brukner Group
Quantum Foundations and Quantum Information Theory

Verstraete Group
Many-Body Quantum Theory

Walther Group
Quantum Information Sciences and Quantum Computation

Zeilinger Group
Quantum Information and Foundation of Physics

Head of Group
Philip Walther | Associate Professor

Quantum Optics, Quantum Nanophysics and Quantum Information
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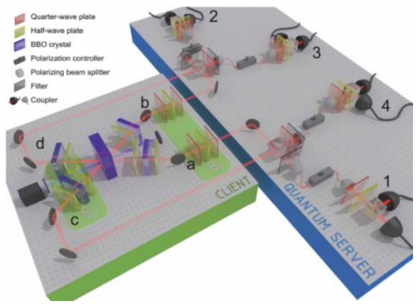
E-Mail

Photonic Quantum Computing

CoQuS
ComplexQuantumSystems

(Secure) Quantum cloud computing

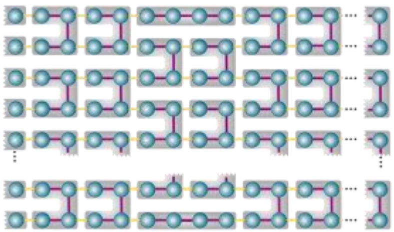


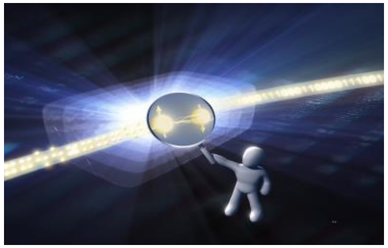
- **Photons as ideal carrier for quantum clouds.**
- **Quantum physics allows secure computing**

Science 335, 303 (2012)

Physics Today 65, 21 (2012)

Verification of quantum computation



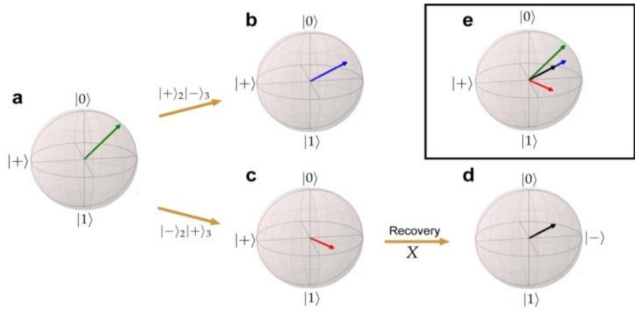


- **Secure quantum computers as new toolbox**
- **Probing underlying mechanism of quantum computer**

Nature Physics 8, 666 (2012)

Nature Physics DOI 10.1038 (2013)

Error Correction for measurement-based quantum computing



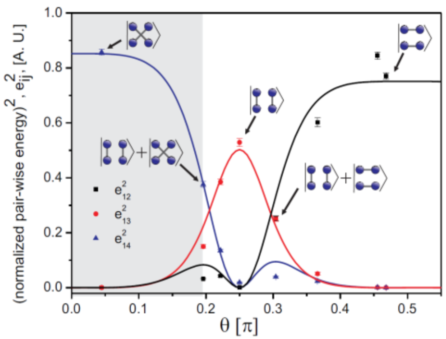
- **redundant encoding of quantum information**
- **resource-efficient tracking (online) of error**

arXiv:quant-ph/1308.5209 (2013)

Photonic Quantum Simulation

CoQuS
ComplexQuantumSystems

Quantum simulation of chemical bonds

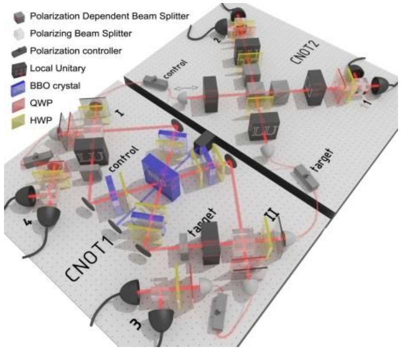


- **simulation of other quantum systems**
- **insights into other quantum systems**

Nature Physics 7, 399 (2011)

Nature Physics 8, 285 (2012)

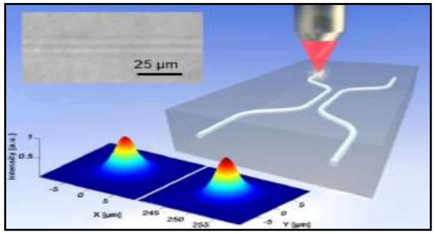
Quantum simulation of XY-interacting spins

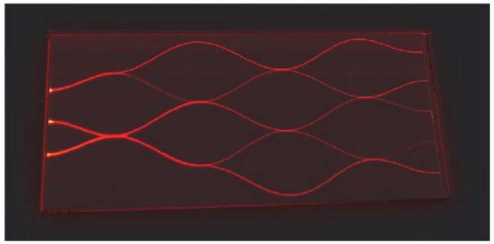


- **2 consequtive CNOT gates**
- **simulation and computation experiments**

quant-ph/arXiv:1302.1210 (2013)

Intermediate quantum computation (resource-efficient)





- **promising candidate for outperforming conventional supercomputers**
- **passive networks and quantum behaviour leads to complex computational problems**

Nature Photonics 7, 540 (2013)

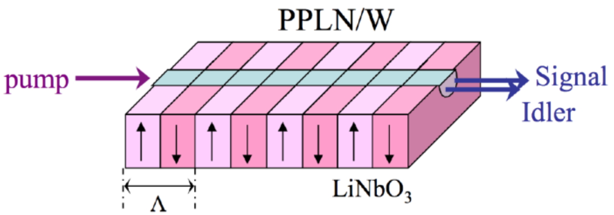
Photonic Quantum Technology Projects

CoQuS ComplexQuantumSystems

Multi-Photon Sources

employing stronger nonlinearities for efficient multi-photon generation

→ **femtosecond-pulsed sources of high brightness**



Solid-state entangled photon source

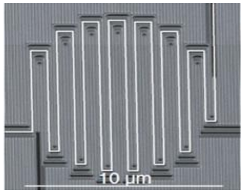
single-photon emission from Nitrogen-vacancy centers in diamond

→ **scalable generation of photonic states (coll. Schmiedmayer/Trupke roup)**

Integrated Quantum Circuits

laser-written waveguides in 3 dimensions enable complex circuitry

→ **integrated processing of polarization-encoded multi-photon states**



Superconducting Detectors

custom-built superfast nanowire detectors based on superconduction

→ **unique multi-photon detection efficiencies (80%-90%)**

Light-Matter Interactions

coupling of narrow-band photons to atoms via evanescent light field

→ **deterministic gates to improve scalability (coll. Rauschenbeutel group)**

EQUAM

Emulators of Quantum Frustrated Magnetism

<u>UniWien:</u>

PI:	Philip Walther
Co-PI:	Stefanie Barz
PostDoc/PhD:	Max Tillmann

WP1: Quantum emulation of geometrically frustrated quantum spin models, aiming for spin liquid states and topological order [24ManMonths]

Task1.2 Small-scale quantum emulation of the quantum XY model with photonic simulators

- Focus on the quantum emulation of the quantum XY, XXZ, and Heisenberg models for few elementary spins on links and subject to transverse magnetic fields.

- Two different strategies for the photonic quantum emulation of many-body systems.
  - use laser-written waveguide structures that enable stable interferometers on the underlying chip.
  - use bulk-optical setups that allow for the precise manipulation of polarization-encoded photons.

- Development of new quantum photonic technology (sources, detectors, waveguides)

- As a first step a photonic quantum computer will be designed and built for simulating the quantum XY model for two spins in a transverse magnetic field.

- Later additional ancilla photons will be used for realizing non-destructive control-not gates to enable the processing of two qubits via consecutive two-qubit gate operations.

Deliverables of WP 1

D1.1 (month 18): Theoretical assessment of realistic conditions for the emulation of spin models

UNIWIEN: Schemes of non-destructive control-not gates by ancillary photons to enable spin-spin interactions and state processing via consecutive two-qubit gate operations.

D 1.2 (month 18): Small-scale emulation of frustrated quantum spin models and ground state tomography

UNIWIEN: Realization of a photonic quantum computer simulating quantum XY model for two spins in a transverse magnetic field. Precise single-qubit control and entangling two-qubit gates will be used to emulate the influence of a transverse magnetic field on such an interacting spin systems.

D 1.4 (month 24): Experimental study of emulation technology improvements, towards large scale systems

UNIWIEN: Development of techniques to perform analog and digital quantum emulations. Customized superconducting nano-wire detectors with detection efficiencies above 80% and novel down-conversion sources with strong nonlinearities to obtain high-fidelity quantum control from six- to eight-qubit states.

D 1.5 (month 30): Experimental emulation of frustrated quantum spin models: realization and detection of the anti-ferromagnetic Néel order

UNIWIEN: Experimental quantum emulation of six-qubit quantum Heisenberg models. Photonic quantum emulation of three interacting valence-bond states, whose interactions are continuously changed by using up to three tuneable directional couplers.

WP2: Quantum emulation of quantum systems with frustration due to competing interactions on different length scales on geometries of increasing complexity [24ManMonth]

Task 2.2: Experimental realization of quantum simulators of frustrated systems with competing long-range interactions (Task leaders: JGUM, UNIULM, UNIWIEN)

- The quantum spin models of Task 1 above will be emulated in realistic conditions using two bottom-up approaches, capable of being scaled up, based on ion crystals and NV centres in diamonds. Small-scale realizations will be assessed and compared with the ones obtained with photonic simulators.

Small-scale realization of quantum spin models with competing interactions by photonic simulators – full tomography and state reconstruction

- Partner UNIWIEN will attack the quantum emulation of frustrated quantum spins due to long-range competing interactions with photonic platforms.
- Development of new photonic quantum technology will need to be developed. We plan to combine bright multi-photon sources based on spontaneous parametric downconversion, tuneable couplers for measurement-induced interactions, and efficient single-photon detectors using superconducting nano-wire technology.
- Digital manipulation of dimer-covering ground state wave functions of Heisenberg-interacting spin systems (plaquette state, six-site checkerboard lattice)

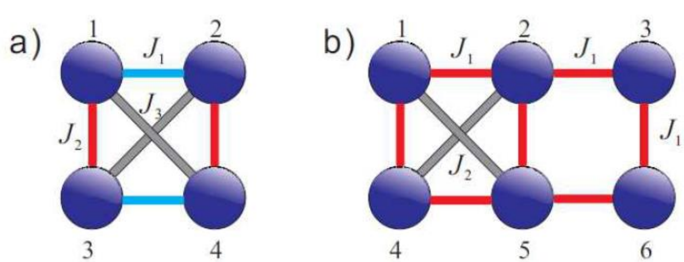
Deliverables of WP 2

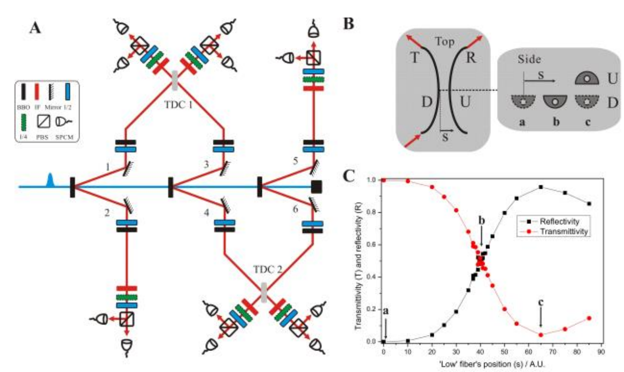
D 2.1 (month 12) Experimental and theoretical techniques for the emulation of spin-spin interactions on different lengths scales

UNIWIEN: Integration of nonlinear crystals for photon-pair generation, tunable directional couplers for continuously tuning measurement-induced interactions, and efficient nano-wire detectors for bright multi-photon detections. Quantum control of four and six polarization-encoded qubits to study competing interactions of different ranges

D 2.4 (month 30) Photonic quantum emulator of ground-state configurations of Heisenberg square and checkerboard lattice spin systems: theory and experiment

UNIWIEN: Analog quantum emulation of ground state configurations of Heisenberg-interacting spins on a square and checkerboard lattice with nearest-neighbour and next-to-nearest-neighbour interactions. Full ground-state tomographic reconstruction.





WP3: Common challenges and methods: theory, assessment, comparison, and integration of quantum simulators [18ManMonths]

D 3.1 (month 18): Optimized schemes for noise and decoherence control (all partners)

D 3.2 (month 24): Optimized schemes for state and process verification from experimental data sets (all partners)

D 3.3 (month 36): Frustration quantifiers and nonlocal entanglement indicators beyond topological entropy: theoretical characterization and experimental comparison (all partners)