EU FP7 - Cooperation - STREP Project EquaM - GA. n. 323714

Emulators of Quantum Frustrated Magnetism

Newsletter 1 – 15/10/2014

Abstract of the project

www.project-equam.eu

Among complex systems with emergent behaviours, frustrated quantum magnets are predicted to exhibit novel, highly nontrivial phases of matter that may play a major role in future and emerging quantum technologies such as the synthesis of innovative materials for energy harnessing and storage, entanglement-enhanced metrology, and topological quantum computing. Unfortunately, due to the intrinsic levels of noise in "natural" compounds, the controlled realization, characterization, and manipulation of frustrated quantum magnets appear exceedingly demanding. On the other hand, we are now entering an advanced stage of development of quantum emulators, engineered quantum systems that realize model Hamiltonians of increasing complexity in a controlled fashion. Cutting-edge technologies for quantum emulation science include cold atoms in optical lattices, trapped ultracold ions (Coulomb crystals), NV centres in diamond, and photonic circuits. By developing, comparing, and integrating these four different atom-optical platforms, project EQuaM's breakthrough is the controlled experimental emulation of fundamental model Hamiltonians for frustrated quantum magnetism, both in nontrivial lattice geometries and for competing long-range interactions, and the characterization of their phase diagrams, targeting fundamental features such as spin liquid phases, global topological order, and fractional excitations. By achieving this objective, EQuaM's groundbreaking contribution to the long-term vision in Information and Communication Technologies (ICT) is the efficient quantum emulation, not admitting efficient classical computational counterparts, of many-body quantum systems with essential elements of complexity. Besides providing crucial insights in the physics of complex many-body systems, it will be a foundational step in the realization of large-scale architectures for topologically protected quantum computation and information.

First year events:

Kick-off meeting, Wien, 4 November 2013
http://www.project-equam.eu/wien.html

First EQuaM spring meeting, Ulm, 8-9 May 2014
http://www.project-equam.eu/ulm.html

Updates on the website:

On the website www.project-equam.eu are available all the relevant updates related to the project. You can find the description of the work packages, the members of the consortium, the talks and presentations of the EQuaM events, the list of publications aknowledging the project and a restricted area which contains the progress report of all partners.
A newsletter service has been implemented, with open access, and available for subscription on the homepage. Everybody can send a message to the community by writing to newsletter@project-equam.eu. You are invited to notify any relevant publication from your node to disseminate among the community.

Highlighted publications and preprints October 2013 - September 2014:

Hybrid sensors based on colour centres in diamond and piezoactive layers

Jianming Cai, Fedor Jelezko & Martin B. Plenio

The ability to measure weak signals such as pressure, force, electric field and temperature with nanoscale devices and high spatial resolution offers a wide range of applications in fundamental and applied sciences. Here we present a proposal for a hybrid device composed of thin film layers of diamond with colour centres and piezoactive elements for the transduction and measurement of physical signals. The magnetic response of a piezomagnetic layer to an external stress or a stress induced by a signal is shown to affect significantly the spin properties of nitrogen-vacancy centres in diamond. Under ambient conditions, realistic environmental noise and material imperfections, we show that this hybrid device can achieve significant improvements in sensitivity over the pure diamond-based approach in combination with nanometre-scale spatial resolution. Furthermore, the proposed hybrid architecture offers novel possibilities for engineering strong coherent couplings between nanomechanical oscillator and solid state spin qubits.

Nuclear magnetic resonance spectroscopy with single spin sensitivity

C. Müller, X. Kong, J.-M. Cai, K. Melentijević, A. Stacey, M. Markham, D. Twitchen, J. Isoya, S. Pezzagna, J. Meijer, J. F. Du, M. B. Plenio, B. Naydenov, L. P. McGuinness & F. Jelezko

Nuclear magnetic resonance spectroscopy and magnetic resonance imaging at the ultimate sensitivity limit of single molecules or single nuclear spins requires fundamentally new detection strategies. The strong coupling regime, when interaction between sensor and sample spins dominates all other interactions, is one such strategy. In this regime, classically forbidden detection of completely unpolarized nuclei is allowed, going beyond statistical fluctuations in magnetization. Here we realize strong coupling between an atomic (nitrogen–vacancy) sensor and sample nuclei to perform nuclear magnetic resonance on four 29Si spins. We exploit the field gradient created by the diamond atomic sensor, in concert with compressed sensing, to realize imaging protocols, enabling individual nuclei to be located with Angstrom precision. The achieved signal-to-noise ratio under ambient conditions allows single nuclear spin sensitivity to be achieved within seconds.

Multiple intrinsically identical single-photon emitters in the solid state

L.J. Rogers, K.D. Jahnke, T. Teraji, L. Marseglia, C. Müller, B. Naydenov, H. Schauffert, C. Kranz, J. Isoya, L.P. McGuinness & F. Jelezko

Emitters of indistinguishable single photons are crucial for the growing field of quantum technologies. To realize scalability and increase the complexity of quantum optics technologies, multiple independent yet identical single-photon emitters are required. However, typical solid-state single-photon sources are inherently dissimilar, necessitating the use of electrical feedback or optical cavities to improve spectral overlap between distinct emitters. Here we demonstrate bright silicon vacancy (SiV^-) centres in low-strain bulk diamond, which show spectral overlap of up to 91% and nearly transform-limited excitation linewidths. This is the first time that distinct single-photon emitters in the solid state have shown intrinsically identical spectral properties. Our results have impact on the application of single-photon sources for quantum optics and cryptography.

Classical nature of ordered phases: origin of spontaneous symmetry breaking

M. Cianciaruso, L. Ferro, S. M. Giampaolo, F. Illuminati

We investigate the nature of spontaneous symmetry breaking in complex quantum systems by conjecturing that the maximally symmetry breaking quantum ground states are the most classical ones corresponding to an ordered phase. We make this argument quantitatively precise by showing that the ground states which realize the maximum breaking of the Hamiltonian symmetries are the only ones that: I) are always locally convertible, i.e. can be obtained from all other ground states by local operations and classical communication, while the reverse is never possible; II) minimize the monogamy inequality for bipartite entanglement; III) minimize quantum correlations, as measured by the quantum discord, for all pairs of dynamical variables and are the only ground states for which the pairwise quantum correlations vanish asymptotically with the intra-pair distance.

Tomography of Band Insulators from Quench Dynamics

Philipp Hauke, Maciej Lewenstein, and André Eckardt

We propose a simple scheme for tomography of band-insulating states in one- and two-dimensional optical lattices with two sublattice states. In particular, the scheme maps out the Berry curvature in the entire Brillouin zone and extracts topological invariants such as the Chern number. The measurement relies on observing—via time-of-flight imaging—the time evolution of the momentum distribution following a sudden quench in the band structure. We consider two examples of experimental relevance: the Harper model with π flux and the Haldane model on a honeycomb lattice. Moreover, we illustrate the performance of the scheme in the presence of a parabolic trap, noise, and finite measurement resolution.

Proposal for Verification of the Haldane Phase Using Trapped Ions

I. Cohen and A. Retzker

A proposal to use trapped ions to implement spin-one XXZ antiferromagnetic chains as an experimental tool to explore the Haldane phase is presented. We explain how to reach the Haldane phase adiabatically, demonstrate the robustness of the ground states to noise in the magnetic field and Rabi frequencies, and propose a way to detect them using their characteristics: an excitation gap and exponentially decaying correlations, a nonvanishing nonlocal string order, and a double degenerate entanglement spectrum. Scaling up to higher dimensions and more frustrated lattices, we obtain richer phase diagrams, and we can reach spin liquid phase, which can be detected by its entanglement entropy which obeys the boundary law.

Spin-orbit coupling in periodically driven optical lattices

J. Struck, J. Simonet, and K. Sengstock

We propose a method for the emulation of artificial spin-orbit coupling in a system of ultracold, neutral atoms trapped in a tight-binding lattice. This scheme does not involve near-resonant laser fields, avoiding the heating processes connected to the spontaneous emission of photons. In our case, the necessary spin-dependent tunnel matrix elements are generated by a rapid, spin-dependent, periodic force, which can be described in the framework of an effective, time-averaged Hamiltonian. An additional radio-frequency coupling between the spin states leads to a mixing of the spin bands.

Linear-optical generation of eigenstates of the two-site XY model

Stefanie Barz, Borivoje Dakic, Yannick Ole Lipp, Frank Verstraete, James D. Whitfield, Philip Walther

Much of the anticipation accompanying the development of a quantum computer relates to its application to simulating dynamics of another quantum system of interest. Here we study the building blocks for simulating quantum spin systems with linear optics. We experimentally generate the eigenstates of the XY Hamiltonian under an external magnetic field. The implemented quantum circuit consists of two CNOT gates, which are realized experimentally by harnessing entanglement from a photon source and by applying a CPhase gate. We tune the ratio of coupling constants and magnetic field by changing local parameters. This implementation of the XY model using linear quantum optics might open the door to the future studies of quenching dynamics using linear optics.

Experimental realization of fast ion separation in segmented Paul traps

T. Ruster, C. Warschburger, H. Kaufmann, C. T. Schmiegelow, A. Walther, M. Hettrich, A. Pfister, V. Kaushal, F. Schmidt-Kaler, and U. G. Poschinger

We experimentally demonstrate fast separation of a two-ion crystal in a microstructured segmented Paul trap. By the use of spectroscopic calibration routines for the electrostatic trap potentials, we achieve the required precise control of the ion trajectories near the critical point, where the harmonic confinement by the external potential vanishes. The separation procedure can be controlled by three parameters: a static potential tilt, a voltage offset at the critical point, and the total duration of the process. We show how to optimize the control parameters by measurements of ion distances, trap frequencies, and the final motional excitation. We extend the standard measurement technique for motional excitation to allow for discriminating thermal and oscillatory states, and to cover a dynamic range covering more than 4 orders of magnitude in energy. It is shown that for fast separation times, oscillatory motion is excited, while a predominantly thermal state is obtained for long times. At a separation duration of 80μs, a minimum mean excitation of n =4.16(0.16) vibrational quanta per ion is achieved, which is consistent with the adiabatic limit given by our particular trap. The presented technique does not rely on specific trap geometry parameters and can therefore be adopted for different segmented traps.