Scientific Area	SA.6 Quantum Simulation
Topic title	Experimental Quantum Simulations based on Trapped Ions (& Atoms)
Main host institution	University of Freiburg https://www.uni-freiburg.de/
Supervisor/institution	Tobias Schaetz / University of Freiburg https://www.qsim.uni-freiburg.de/
Co-Supervisor/institution	Heinz-Peter Breuer / University of Freiburg http://www.quantum.uni-freiburg.de/
Mentor[1]/institution	Guido Pupillo / University of Strasbourg https://isis.unistra.fr/laboratory-of-quantum-physics/
Secondment institution	PTB: https://www.quantummetrology.de/nc/eqm/staff/piet-schmidt Hübner GmbH: https://www.hubner-group.com/en

Topic description

Direct experimental access to the most intriguing and puzzling quantum phenomena is extremely difficult and their numerical simulation on conventional computers can easily become computationally intractable. However, one might gain deeper insight into complex quantum dynamics via experimentally simulating and modelling the quantum behaviour of interest in a second quantum system. There, the significant parameters and interactions are precisely controlled and underlying quantum effects can be detected sufficiently well, thus, their relevance might be revealed. Trapped atomic ions have been shown to be a unique platform for quantum control, evidenced by the most precise operations of quantum information processing and their performance as best atomic clocks.

Still, scaling is the major challenge – i.e. the endeavour to control increasingly large systems of particles at the quantum level will be one of the driving forces for physical sciences in the coming decades. We aim to control charged atoms at the highest level possible to further scale many-body (model) systems ion by ion. This approach is, in a way, the ultimate form of engineering - in radio-frequency traps, as well as in all-optical traps, when combined with ultra-cold atoms.
Here we propose two alternative experimental projects, both in close collaboration with theorists:
(i) We aim at exploiting the extended-dimensionality and tuneable interaction at long range in our basic array of individually trapped and controlled ions, scalable in established CMOS technology [Nat.Commun.7, 11839 (2016), Phys.Rev.Lett.123, 213605 (2019) and Phys.Rev.Lett.123 100504 (2019)]. The plan is to first further investigate the correlations of complexity and scaling, ion by ion, followed by tackling paradigmatic effects in solid state physics, such as, spin-frustration in triangular lattices or quantum dynamics of tunnelling phonons and related Aharonov-Bohm physics to simulate artificial gauge fields [Phys.Rev.Lett.107, 150501 (2011)].
(ii) Complementarily, we seek to gain insight into the interaction between ultra-cold atoms and ions in purely optical traps [Phys. Rev. Lett. 124, 053402 (2020)] and into the counter-intuitive emergence of thermalisation in closed quantum systems and its timescales [Phys. Rev. Lett. 117, 170401 (2016), Nature 551, 20 (2017)].

Recommended applicant's profile

Experience in AMO-physics and knowledge in quantum control are appreciated, however, not required. Vivid interest in quantum effects and technologies are prerequisites.

[1] Mentor: The primary role of the mentors will be to identify and facilitate specific training objectives, advise on any problems faced by the ESR, including career matters with an external perspective and provide mediation in the case of disputes.

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