Quantum simulation – Engineering & understanding quantum systems atom-by-atom

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Quantum simulation provides new insights into the complex properties of quantum many-body systems in regimes that are not accessible with state-of-the-art classical numerical methods.

In this talk, I will introduce quantum simulators based on ultracold atoms in optical lattices, where control at the level of individual particles can now be achieved in systems of several thousand atoms. I will discuss how these platforms enable the exploration of topological phases of matter and their interplay with interactions and disorder [1-3]. I will further present recent results on the preparation of non-equilibrium U(1) quantum spin liquids of Rokhsar-Kivelson type and their connection to lattice gauge theories.

Finally, I will highlight recent experimental advances that provide new ways to prepare and probe complex quantum states [4,5], opening routes to the study of strongly correlated and out-of-equilibrium many-body physics, where neutral-atom platforms not only emulate but are starting to enable new discoveries of complex quantum phenomena.

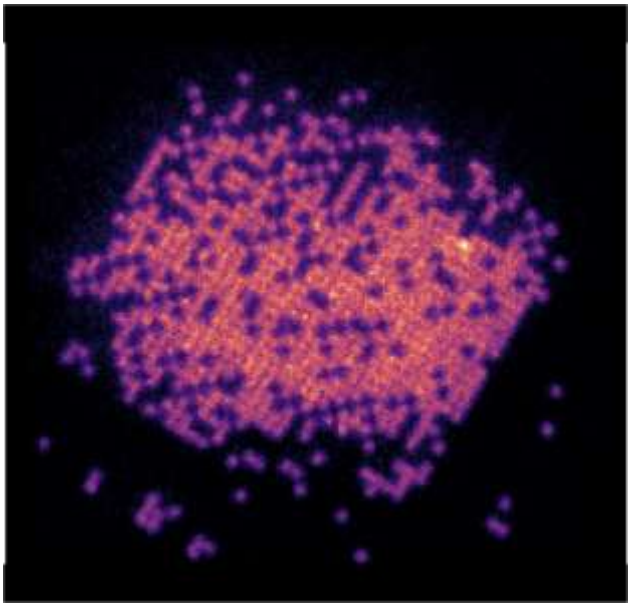

Figure 1: Fluorescence image of ultracold Cs atoms in an optical lattice

References

[1] A. Impertro et al., Nature Physics 21, 895-901 (2025).
[2] C. Braun et al., Nature Physics 20, 1306-1312 (2024)
[3] A. Hesse et al., arXiv: 2508.20154 (2025)
[4] A. Impertro et al., Phys. Rev. Lett. 133, 063401 (2024)
[5] S. Karch et al., arXiv:2501.16995 (2025)