

Call 2021
Final Evaluation



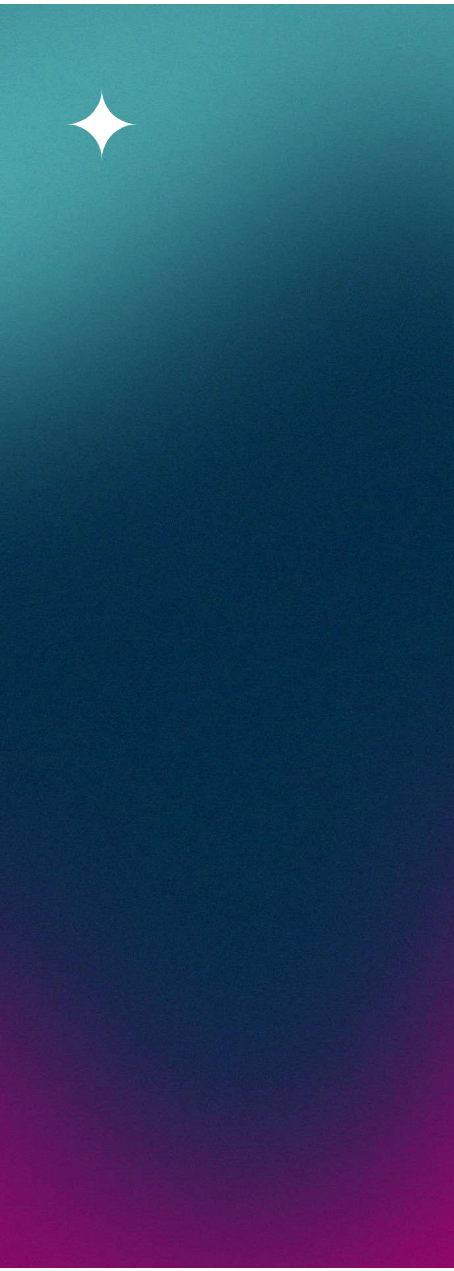
DYNAMITE

Next-Generation Quantum Simulators:
From DYNAMIcal Gauge Fields to Lattice Gauge
ThEory

Maciej Lewenstein

Website : <https://dynamite-project.eu/team/>

Social Media Platform X:



COLLABORATION (overview)



GEOGRAPHICAL BREADTH:

Spain, POLAND, Germany x 2, Italy, Switzerland



VARIETY OF SECTORS, DISCIPLINES: Atomic, Molecular, Optical Physics, Condensed Matter Physics, High Energy Physics, Quantum Information, Artificial Intelligence, Machine Learning, Statistical Physics



QUALITY OF COOPERATION: Cooperation was very effective and perfectly coordinated, which was expressed in the number of joint publications, consortium meetings, and mobility activities



INFRASTRUCTURE SHARING: All theoretical methods, programs, etc. were open to everyone; experimentalists shared experience and collaborated directly through mobility activities.





SUCCESS STORY (highlights)

CHALLENGE, SOLUTION, PLANNED AND SURPRISING/UNPLANNED OUTCOMES



DYNAMITE pursues three fundamental goals: designing, building in the lab, and studying a new generation of Quantum Simulators focused on ultracold atomic systems, including Rydberg atoms, trapped ions, etc. These systems target the following general goals and breakthroughs, with increasing experimental complexity: Quantum simulation of topological gauge theories, Quantum simulation of dynamical lattices, and Quantum simulation of lattice gauge theory models. In line with this mission, the ICFO/UJ/UniTn/ICTP has continued efforts on topological properties of 1D bosonic and fermionic chains. This endeavor extends to investigating their dynamic response to periodic driving. We developed theory of many-body localization in various systems, including those related to Lattice Gauge Theories (LGT). We designed LGT simulators using dynamical decoupling and qudit systems. Additionally, we have expanded into quantum simulation, exploring the Hubbard-Holstein model, the Abelian-Higgs model, and attoscience. We have harnessed a novel machine-learning approach to explore the intricacies of many-body systems. The collaborative efforts of UniTn and UH have introduced a new toolbox for analyzing complex experimental outcomes using a combination of non-parametric learning methods, establishing a cross-disciplinary link between quantum experiments and other fields. The tools have wide applicability, and experimental data on the dynamics of Bose-Einstein condensates demonstrated their effectiveness in identifying relevant information and critical behavior without ad hoc assumptions.

SUCCESS STORY (highlights)

CHALLENGE, SOLUTION, PLANNED AND SURPRISING/UNPLANNED OUTCOMES



A notable collaboration with the experimental group of Jian-Wei Pan and Zhen-Sheng Yuan in Hefei has yielded significant results in implementing a topological vacuum angle within an Abelian gauge theory. This implementation, realized within an optical lattice, has enabled the microscopic observation of a confinement—deconfinement transition. The theory team at LMU has turned our attention to the long-sought goal of realizing non-Abelian lattice gauge theories. Building on previous work by DYNAMITE members, we analyzed the possibility of stabilizing non-Abelian $SU(N)$ or $U(N)$ gauge invariance through suitable gauge-protection schemes: undesired gauge sectors are detuned energetically to ensure emergent low-energy physics in the gauge-invariant subspace. In the work titled “Spin exchange-enabled quantum simulator for large-scale non-Abelian gauge theories,” we have demonstrated that $SU(N)$ spin-exchange interactions — readily available in cold-atom quantum simulation setups — are sufficient to achieve reliable protection of $SU(N)$ gauge theories and realize interesting Hamiltonians. Moreover, together with our experimental colleagues, we have developed realistic experimental protocols for implementations of $SU(2)$ theories with ultracold fermionic atoms in state-dependent optical lattices and extended the approach to simulate $SU(N)$ theories in a hybrid digital-analog simulator based on Rydberg atoms. This paved the way for near-term implementation of such models with bosonic or fermionic matter, as the DYNAMITE consortium seeks.



SUCCESS STORY (highlights)

CHALLENGE, SOLUTION, PLANNED AND SURPRISING/UNPLANNED OUTCOMES



Recent progress in developing such an experimental platform at LMU has been reported in two recent publications that appeared in **Phys. Rev. Res. (2025)** and **PRX Quantum (2026)**. We also summarized the current state of the art in a review article in **Nature Physics (2025)**. Overall, the project addresses one of the 4 pillars of Quantum Technologies (QT): quantum simulation. The expected impact consists of **deepening the fundamental/practical understanding of quantum simulators and their relevance for QT, enhancing the robustness and scalability of simulators as a part of QT, and enhancing interdisciplinarity in crossing traditional boundaries between areas: AMO physics, quantum optics, condensed matter, nuclear and high energy physics, material science.**

SCIENTIFIC OUTPUTS



PUBLICATIONS AND PRESENTATIONS (highlights)

69 papers were reported in the Final Report, most in top Q1 journals



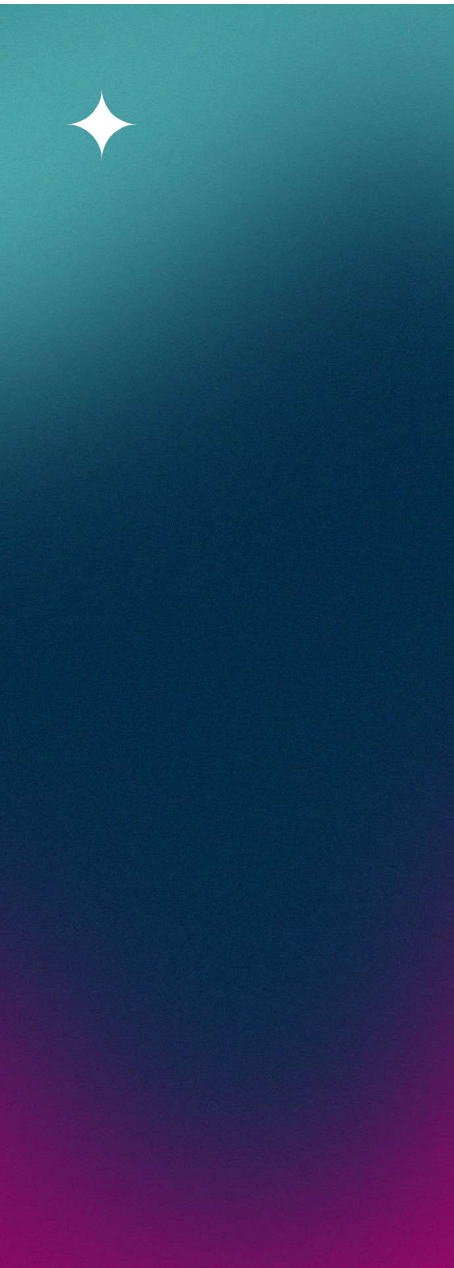
PATENTS (obtained and pending)

DYNAMITE dealt with fundamental aspects, and no patents were obtained/are pending



NUMBER OF BACHELOR, MASTER AND PhD THESES prepared under the QuantERA Project

Only at ICFO-QOT: 6 MSc and 2 BSc theses, and 10 PhD theses defended. Altogether, the numbers are at least twice as large.



IMPACT (potential users)

RELEVANT **INDUSTRY BRANCH**



Basic pillars of quantum technologies: Quantum Simulations and Quantum Computing



KEY COMMERCIALY RELEVANT **APPLICATIONS**



Basic future applications: Benchmarking of quantum computers (see new Qantera's in preparation)



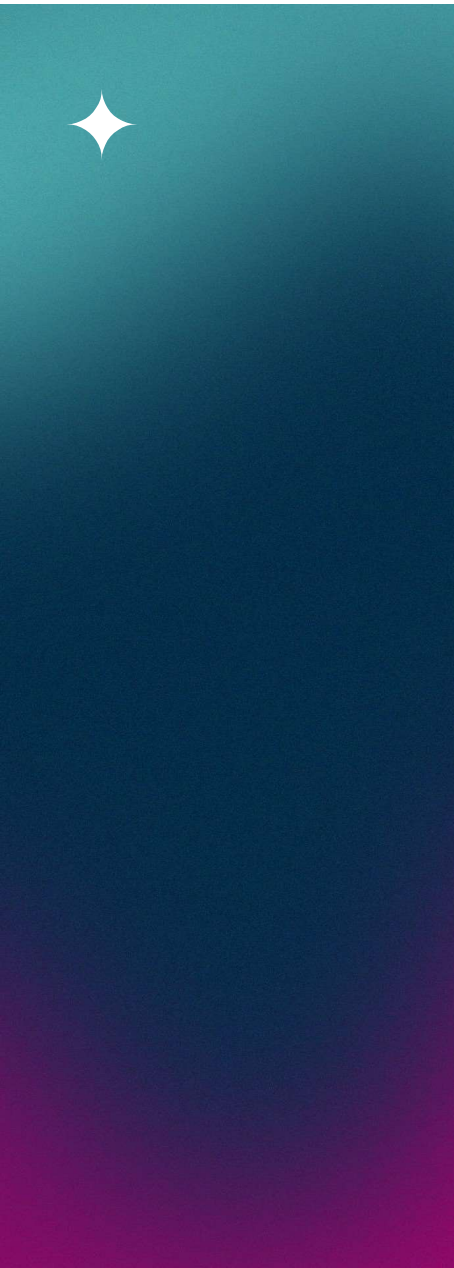
EXISTING/POTENTIAL **END USERS**

Quantum technologies industry

COOPERATION WITH THE **QUANTUM FLAGSHIP**
OR OTHER QUANTUM INITIATIVES (if applicable)

Very fruitful: the majority of members were participating in PASQUAN and PASQUAN2





IMPACT (RRI aspects)

GENDER: fostering gender balance in research teams

Active fostering of gender balance. For instance, my group from 2023-2026 includes 50-70% female members)



OPEN SCIENCE: promoting transparency and reproducibility of research, increasing and widening the diffusion of knowledge



For instance, an active program of sonification of quantum processes at ICFO. Outreach and deeper understanding of quantum technologies



SCIENCE EDUCATION: making science education and careers attractive for young people



The numbers of MSc, BSc, and PhDs say for themselves!

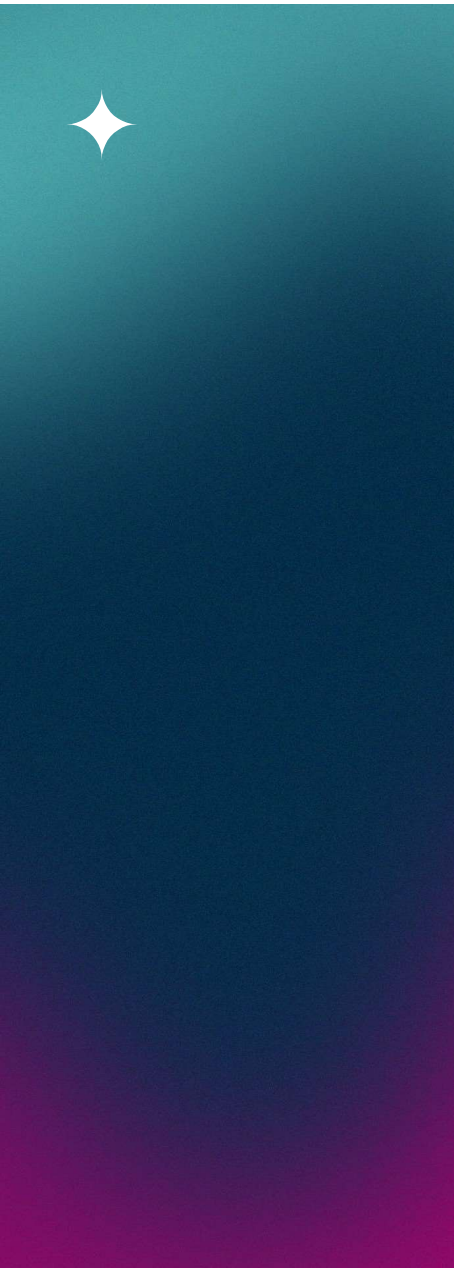
PUBLIC ENGAGEMENT: creating 2-way, inclusive and participatory multi-actor dialogues between researchers, policy makers, industry and civil society, NGOs and citizens



Very active outreach programs; see, for instance, ICFO

ETHICS: applying fundamental ethical principles and legislation to scientific research

Very active ethics committees in all involved institutions



WHAT'S NEXT

Continuation with/without members of the consortium

At least two new QUANTERAs in preparation/applied:

Quantum Simulators of Lattice Gauge Theories for Benchmarking Quantum Computers.

For the ideas, see

Barbara Andrade, Declan Millar, Lewis Anderson, Vincent R. Pascuzzi, Maciej Lewenstein, Ivano Tavernelli, Jad C. Halimeh, and Tobias Grass, Dynamic Induction of Lattice Gauge Theories on a Quantum Computer, [arXiv:2608.02756v1](https://arxiv.org/abs/2608.02756).

Thank You for Your Attention!

