



## La lettre du Collège de France

8 | mars 2014  
Collège de France Newsletter n°8

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# “Ultracold Quantum Matter” Project (UQUAM)

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### Electronic version

URL: <https://journals.openedition.org/lettre-cdf/2003>

DOI: 10.4000/lettre-cdf.2003

ISSN: 2109-9219

### This article is a translation of:

Projet « Ultracold Quantum Matter » (UQUAM) - URL : <https://journals.openedition.org/lettre-cdf/1652> [fr]

### Publisher

Collège de France

### Printed version

Date of publication: 1 March 2014

Number of pages: 22

ISSN: 1628-2329

### Electronic reference

Jean Dalibard, ““Ultracold Quantum Matter” Project (UQUAM)”, *La lettre du Collège de France* [Online], 8 | mars 2014, Online since 11 August 2015, connection on 17 August 2022. URL: <http://journals.openedition.org/lettre-cdf/2003> ; DOI: <https://doi.org/10.4000/lettre-cdf.2003>

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## EDITOR'S NOTE

Source: La lettre, no. 36, May 2013

- 1 **In 2012, the European Research Council (ERC) launched a call for proposals, named Synergy, with the aim of promoting collaborative research between European research groups. Our team, which is currently working on Bose-Einstein condensates at the Kastler Brossel Laboratory, is part of the fortunate eleven winning consortiums, with a theme that may seem a little mysterious: ultra-cold quantum matter.**
- 2 The starting point of this project is the interaction between light and matter. This interaction has always been crucial to understanding our environment. Quantum physics, which successfully describes the microscopic world, developed thanks to the analysis of the light emitted and absorbed by an assembly of atoms or molecules. But only for the last 20 years or so have we known how to manipulate and control individual quantum systems, an atom or a photon, the elementary grain of light. This very progress earned our *Administrateur* Serge Haroche and David Wineland the 2012 Physics Nobel Prize.
- 3 In a visionary text written in the eighties, the physicist Richard Feynman explained the full value of having the same control, but for a large number of particles. The artificial matter thus produced could allow us to address some major questions, both fundamental and practical, which currently remain unanswered. Let me mention two: with a better understanding of the phenomenon of supra-conductivity, could we design materials that transport electricity without any loss, for everyday applications? By using quantum concepts wisely, could we develop new memories that could store much larger quantities of information than our current hard drives?



- 4 Why do these quantum systems with a large number of particles present such a challenge? We know how the particles interact with one another, and we have no difficulty of principle to describe the behaviour of small groups. However, quantum complexity makes it extremely difficult to describe a large assembly. Consider a chain of 100 spins, in other words 100 microscopic magnets which can exist in two configurations, with the north pole on top or at the bottom. Merely writing the general quantum state of this chain would require a computer larger than all those currently operational. And doing calculations on this quantum state seems even more unrealistic...
- 5 Feynman proposed another approach, quantum simulation, which is at the heart of our Synergy project. It is founded on the universality of quantum physics; two seemingly different systems can be described through a similar formalism if they share certain parameters: for example, the ratio of the interaction energy and the temperature, or their geometry (linear, plane or voluminal). Our quantum system model is formed of an assembly of ultra-cold atoms, trapped in a light wave. These cold atoms are prepared using mechanisms identified by Claude Cohen-Tannoudji in particular (professor at the Collège de France and 1997 Physics Nobel Prize Laureate). They are produced at a temperature only a few billionths of a degree above absolute zero. Using light beams, the atoms are organized into "landscapes" which simulate other environments: periodic to model the electrons of a crystal, or disorganized to study propagation in a random environment. By forming an alignment of a hundred atoms, the chain of spins described above can thus be simulated. The system is left to evolve freely for a given amount of time and its final state is measured. Nature does the calculation for us, and the above-mentioned universality ensures that the result obtained for our atoms is also valid for the system modelled.
- 6 Our consortium selected for the Synergy project is comprised of two teams of theoretical physicists, led by Peter Zoller in Innsbruck and Ehud Altman at the Weizmann Institute in Israel, and of two teams of experimentalists, that of Immanuel Bloch in Munich and ours, which will soon be moving into the Physics Institute of the Collège de France. We could not hope for better support than the help we have received from the ERC, which will very soon allow us to begin these new experiments in this entirely renovated building.

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AUTHOR

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Atoms and Radiation