

**UNIVERSITÀ DEGLI STUDI DI MILANO**

selezione pubblica per n. 1 posto di Ricercatore a tempo determinato in tenure track (RTT) per il gruppo scientifico-disciplinare 01/MATH-04 - Fisica matematica , settore scientifico-disciplinare MATH-04/A - Fisica matematica presso il Dipartimento di MATEMATICA "FEDERIGO ENRIQUES", (avviso bando pubblicato sulla G.U. IV serie speciale Concorsi ed Esami del 12.11.2024) Codice concorso 5647

## Alexander Bols

### CURRICULUM VITAE

**PERSONAL DATA (DO NOT INCLUDE YOUR PERSONAL ADDRESS AND LANDLINE OR MOBILE PHONE NUMBER)**

<b>SURNAME</b>	BOLS
<b>NAME</b>	ALEXANDER
<b>DATE OF BIRTH</b>	07/09/92
<b>Citizenship</b>	Belgian

### QUALIFICATIONS

#### **DEGREE**

degree name : Master of Physics (Master of Science)  
result : Magna cum laude  
university : KULeuven  
date : 02/07/2015

**DOCTORAL DEGREE OR EQUIVALENT QUALIFICATION EARNED IN ITALY OR ABROAD / MEDICAL SPECIALISATION DIPLOMA OR EQUIVALENT QUALIFICATION, FOR THE RELEVANT SECTORS, EARNED IN ITALY OR ABROAD**

degree name : Doctor of Science (PhD)  
university : KULeuven  
date : 16/05/2019

**RESEARCH CONTRACTS, RESEARCH FELLOWSHIP CONTRACTS, POSTDOCTORAL SCHOLARSHIPS OR SIMILAR CONTRACTS**

1. postdoctoral position at Copenhagen university  
start : 01/09/2019      end : 31/08/2022
2. postdoctoral position at California Institute of Technology (Caltech)  
start : 07/09/2022      end : 30/06/2023
3. postdoctoral position at ETH Zurich  
start : 01/09/2023      end : ongoing

#### **POSITIONS OFFERED**

2024 - Tenure track at the Faculty of Physics of the Jagiellonian University, Poland

## TEACHING ACTIVITIES AT ITALIAN OR FOREIGN UNIVERSITIES

### As course responsible

- Advanced Mathematical Physics at Copenhagen university, spring 2020
- Advanced Mathematical Physics at Copenhagen university, spring 2022

### As teaching assistant

- Thermodynamics at KULeuven
- General Physics I at KULeuven
- General Physics II at KULeuven
- Capita Selecta in Theoretical Physics at KULeuven
- Mathematical Physics at KULeuven
- Complex Functions at KULeuven

### As project supervisor

- Master thesis ``Absolute continuity of the edge spectrum of disordered Landau Hamiltonians from index theory" (Copenhagen university)
- Bachelor project ``Stability of the solar system" (KULeuven)
- Bachelor project ``Percolation theory and phase transitions" (KULeuven)
- Bachelor project ``the eigenstate thermalization hypothesis" (KULeuven)
- Thesis project 'Topological insulators with long range interactions' (ETH)
- Thesis project 'Electrodynamics as a world view' (ETH)
- Thesis project 'Helmholtz's theory of vortices' (ETH)
- Thesis project 'Vortex theory of the atom' (ETH)
- Thesis project 'The geometry of nature : fractals' (ETH)
- Thesis project 'Geometric phase transitions : percolation (ETH)
- Thesis project 'Central limit theorem' (ETH)
- Thesis project 'Levy distributions' (ETH)

## DEVELOPMENT OF TEACHING MATERIALS

Lecture notes, exercises , and assignments on the integer quantum Hall effect for the course 'Advanced Mathematical Physics', taught at Copenhagen University. The teaching materials can be found [here](https://drive.google.com/drive/folders/1EPZpyhEFq3OrBR6qly_aomZuyUEdtboY?usp=drive_link). ([https://drive.google.com/drive/folders/1EPZpyhEFq3OrBR6qly\\_aomZuyUEdtboY?usp=drive\\_link](https://drive.google.com/drive/folders/1EPZpyhEFq3OrBR6qly_aomZuyUEdtboY?usp=drive_link))

## ATTESTED TRAINING OR RESEARCH ACTIVITIES AT QUALIFIED ITALIAN OR FOREIGN INSTITUTIONS

- Teacher assistant training  
As part of the doctoral training programme at the Arenberg Doctoral School (KULeuven)  
academic year 2015-2016
- Course for teaching assistants  
at Copenhagen university  
academic year 2019-2020

## SPEAKING AT NATIONAL AND INTERNATIONAL CONFERENCES AND CONVENTIONS

**Invited speaker** at for the Many-Body Quantum Systems and Condensed Matter Physics Session of the ICMP (International Conference of Mathematical Physics) in Strassbourg, France. (1/6/2024 - 6/6/2024)

**Invited speaker** at conference ``Solid Math 2022" in Trieste, Italy. (06/09/2022 - 09/09/2022)

**Invited speaker** at conference ``AMS-EMS-SMF Joint International Meeting" in Grenoble, France. (18/07/2022 - 22/07/2022)

**Invited speaker** at Banff workshop "Topological phases of interacting quantum systems" in Oaxaca, Mexico. (2/6/2019 - 7/6/2019)

**Invited speaker** at school "Arizona School of Analysis and Mathematical Physics" in Tucson, Arizona. (05/03/2018 - 09/03-2018)

**Invited speaker** at "Hagedorn Fest" in Blacksburg, Virginia. (20/5/2019 - 24/5/2019)

speaker at workshop "TOPO23" in Tuebingen, Germany. (27/11/2023 - 08/12/2023)

Invited speaker at conference "Quantissima in the Serenissima IV" in Venice, Italy. (22/08/2022 - 26/08/2022)

speaker at conference "ICMP Young Researcher Symposium" in Geneva, Switzerland. (02/08/2021 - 07/08-2021)

speaker at the "Belgian Quantum Physics Initiative" in Brussels, Belgium (13/12/2018)

speaker at the "Belgian Quantum Physics Initiative" in Brussels, Belgium (18/1/2018)

## SEMINARS

(18/01/2024) The Quantum Lattice Seminar (online).

(25/09/2024) Copenhagen University, Quantum Lunch seminar.

(4/04/2024) University of Rome Tor Vergata, Mathematical Physics Seminar.

(27/09/2023) Copenhagen University, Quantum Lunch seminar.

(25/04/2023) Michigan State University, Mathematical Physics and Operator Algebras Seminar.

(18/04/2023) UC Davis, Mathematical Physics Seminar.

(01/11/2022) The Quantum Lattice Seminar (online).

(12/03/2021) The Quantum Lattice Seminar (online).

(24/01/2019) University of Tübingen, Mathematical Physics Seminar.

(09/01/2019) Copenhagen University, Quantum Lunch seminar.

## INTERNATIONAL COLLABORATION

Copenhagen University (Denmark)  
UC Davis (USA)  
Michigan State University (USA)  
University of British Columbia (Canada)  
Princeton University (USA)  
KU Leuven (Belgium)  
Cardiff University (UK)  
Heinrich Heine University (Germany)

## SERVICE

Co-organizer of the quantum lattice seminar.  
referee for Journal of Mathematical Physics (JMP) and Communications in Mathematical Physics (CMP)

## SCIENTIFIC PRODUCTION

1 PhD thesis, 11 publications in peer reviewed journals, 4 preprints.  
citations : 182; h-index : 7; i10-index : 6 (according to Google Scholar on 09/12/2024)

## SCIENTIFIC PUBLICATIONS

1. A. Bols, W. De roeck, ``Asymptotic Localization in the Bose-Hubbard Model", Journal of Mathematical Physics, 2018, doi:10.1063/1.5022757
2. S. Bachmann, A. Bols, W. De Roeck, M. Fraas, ``Quantization of conductance in gapped interacting systems", Annales Henri Poincare, 2018, doi:10.1007/s00023-018-0651-0
3. A. Bols, ``Quantization of Charge Transport in Gapped Ground States" PhD Thesis, 2019, Leuven. <https://lirias.kuleuven.be/retrieve/538314>
4. S. Bachmann, A. Bols, W. De Roeck, M. Fraas, ``A Many-Body Index for Quantum Charge Transport", Communications in Mathematical Physics, 2019, doi:10.1007/s00220-019-03537-x
5. S. Bachmann, A. Bols, W. De Roeck, M. Fraas, ``Note on linear response for interacting Hall insulators", Analytic Trends in Mathematical Physics, 2020, doi:10.1090/conm/741/14918
6. S. Bachmann, A. Bols, W. De Roeck, M. Fraas, ``Many-body Fredholm index for ground-state spaces and Abelian anyons", Physical Review B, 2020, doi:10.1103/PhysRevB.101.085138
7. S. Bachmann, A. Bols, W. De Roeck, M. Fraas, ``Rational indices for quantum ground state sectors", Journal of Mathematical Physics, 2021, doi:10.1063/5.0021511
8. A. Bols, A. Werner, ``Absolutely continuous Edge Spectrum of Hall Insulators on the Lattice", Annales Henri Poincare, 2021, doi:10.1007/s00023-021-01097-2
9. A. Bols, J. Schenker, J. Shapiro, ``Fredholm Homotopies for Strongly-Disordered 2D Insulators", Communications in Mathematical Physics, 2022, doi:10.1007/s00220-022-04511-w
10. A. Bols, B. Kjaer, A. Moon, ``The double semion state in infinite volume", Annales Henri Poincare, 2024, doi.org/10.1007/s00023-024-01445-y
11. A. Bols, C. Cedzich, ``Absolutely continuous edge spectrum of topological insulators with an odd time-reversal symmetry", Letters in Mathematical Physics, 2024, doi.org/10.1007/s11005-024-01846-4

## PREPRINTS

1. A. Bols, ``Classification of equivariant quasi-local automorphisms on quantum chains" ([arXiv:2106.02145](https://arxiv.org/abs/2106.02145))
2. A. Bols, C. Cedzich, ``Absolutely continuous edge spectrum of topological insulators with an odd time-reversal symmetry" ([arXiv:2203.05474](https://arxiv.org/abs/2203.05474))
3. A. Bols, S. Vadnerkar, ``Classification of the anyon sectors of Kitaev's quantum double model" ([arXiv:2310.19661](https://arxiv.org/abs/2310.19661))
4. S. Bachmann, A. Bols, M. Rahnema, ``Many-Body Fu-Kane-Mele index" ([arXiv:2406.19463](https://arxiv.org/abs/2406.19463))

## RESEARCH INTERESTS

My research is concerned with the classification of topological phases of matter such as quantum Hall phases and topological orders. The focus is on understanding these phases from a microscopic point of view in the context of quantum lattice systems, aiming to obtain rigorous results.

In this context, a topological phase is defined to be an equivalence class of gapped local Hamiltonians on a quantum lattice system of some fixed spatial dimension, with two such Hamiltonians being *adiabatically equivalent* if they can be deformed into each other through a path of uniformly gapped Hamiltonians. The gap protects robust entanglement patterns in the ground states of such Hamiltonians, and these 'patterns' can be used to distinguish different topological phases. The ultimate goal is to obtain a complete classification of topological phases in all dimensions. This classification problem can be further refined by imposing a *global symmetry*. For example, imposing a global  $U(1)$  symmetry allows one to talk about quantum Hall phases.

This classification problem is essentially solved in spatial dimensions zero and one, where only one 'trivial' phase exists. In two dimensions, there is a rich landscape of topological phases distinguished by physically meaningful invariants such as *anyonic excitations*, and a *chiral central charge*. The anyonic excitations hosted by a gapped ground state have non-trivial fusion and braiding properties which are believed to be described by a unitary modular tensor category (UMTC), the chiral central charge can be understood heuristically by the belief that if a 2d gapped Hamiltonian is restricted to a half-plane, then the restricted model has low-energy excitations near the boundary whose effective dynamics is described by 'half' of a conformal field theory, i.e. the boundary supports chiral modes and the chiral central charge measures the 'total chirality'. From a mathematical physics point of view, the chiral central charge of gapped quantum lattice systems is very poorly understood. It is believed that the anyon theory and the chiral central charge together form a complete invariant for topological phases in two dimensions, but a proof is currently far out of reach.

In three dimensions the anyon theory generalizes to allow topological excitations that live on both points and lines. These topological excitations are believed to organise in a braided fusion 2-category, a conjecture which is currently the subject of intense study in the physics literature. A rigorous construction assigning a braided fusion 2-category to a gapped three dimensional quantum lattice system is currently not available in the literature. It is not known if this braided fusion 2-category would be a complete invariant for the classification problem in three dimensions.

Finally, it is believed that all gapped systems that are in a non-trivial topological phase host interesting physics on their boundaries. For example, in the case of quantum Hall phases this boundary physics manifests itself as persistent edge currents. For systems with a chiral central charge the heuristics suggest that they host chiral edge modes on their boundaries. Systems that host anyons have boundaries that 'condense' the bulk anyons in interesting ways. An important line of research is to develop stand-alone models of such boundaries and to set up a structure theory/classification program for them.

My research goals are then

- Further develop the theory of anyons in two-dimensional gapped quantum lattice systems.
- Develop a rigorous theory of topological point and line excitations in three-dimensional quantum lattice systems.
- Develop a structure theory for one-dimensional boundary models (i.e. boundaries of two-dimensional topological phases). In particular, achieve a microscopic understanding of the chiral central charge from the boundary point of view. This research project is the subject of an **ongoing ERC starting grant application**.

Date

09/12/24

Place

Zurich, Switzerland