# ANNUAL **REPORT** 2025

Instituts Internationaux
de Physique et de Chimie
fondés par Ernest Solvay ASBL

Internationale Instituten
voor Fysica en Chemie
gesticht door Ernest Solvay VZW

INTERNATIONAL
SOLVAY
INSTITUTES
BRUSSELS

# Annual Report

# 2025

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de Physique et de Chimie
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SOLVAY

"There are no limits to what science can explore"

Ernest Solvay

The international Solvay Institutes for Physics and Chemistry founded by Ernest Solvay, acknowledge with gratitude the generous support of

# THE SOLVAY FAMILY

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The Discovery
of Aspartame
Serendipity

# The Belgian National Lottery

## and the International Solvay Institutes: a long-term partnership

The Belgian National Lottery is one of the main philanthropic organizations in Belgium, which has consistently supported the activities of the International Solvay Institutes for decades. We gratefully acknowledge all those who make this support possible.

This support contributes to the international visibility of Belgium. Most of the greatest chemists, physicists and biologists of the 20th and 21st century have come to Brussels to participate in the prestigious "Solvay Congresses", the pictures of which are known worldwide and have become a symbol of excellence. The Solvay Conferences have put Brussels on the scientific world map.

The support of the National Lottery also paves the way for the future of our society. Investment in scientific knowledge and brainpower is more crucial than ever. Specific activities of the Institutes targeted to inspire the young generations towards science as well as to develop training through research (Colloquia, open Workshops, Public Lectures) directly benefit from the support of the National Lottery.

# A word from the president

The world is changing. So will the Solvay international Institutes for Physics and Chemistry. We are getting ready for a changing world. A world where change is accelerating. This is a century, we are convinced, where at the interconnecting boundaries of fundamental Biology, Physics and Chemistry, science will push out the boundaries of knowledge. This will accelerate with the increased numbers of scientists worldwide and with the new experimental technologies, machine learning and data analysis. But the people, managing the machines and the new technologies will remain the key to insight and discovery.

We believe that the Solvay Institutes are uniquely positioned to bring together the most brilliant scientists to collaborate to solve the most compelling problems at the boundaries of Physics, Biology and Chemistry. Our Conferences are in-person because our humanity is still the most important element in the room. Our model is all about people connecting with each other, sharing insight, listening, collaborating and sharing a joyous meal.

But as Marc, the director, writes in his annual word, we will need a different administrative model to manage our expanding activities and to adapt to the pace of change that will occur in the future. In this, we will need your support for two reasons:

1. As state aid is becoming ever sparser, it will have to be replaced with private financial support. We will engage in fund raising to provide the sustainable resources needed to support our activities.

2. As Science and evidence-based research are increasingly being contested and attacked with disinformation for personal gain, engagement for science is more necessary than ever. Your public support, expressed with your attendance to our various activities, is extremely appreciated.

In 2027, we will celebrate the 100 year anniversary of the 5$^{th}$ Solvay conference on physics where quantum mechanics emerged between the conversations of Einstein, Bohr, Heisenberg and other famous personalities. We have numerous events scheduled for October 2027. We hope to see you there.

I wish to express my deep gratitude to our Sponsors, the ULB and the VUB Universities, the Syensqo Company, the UCB Company, The Belgian National Lottery, BNP-Paribas-Fortis, the FWO, the FNRS, the Brussels Region, the Fédération Wallonie-Bruxelles, and the Solvac Company.

Finally, I want to thank the director, Marc Henneaux, for his tireless daily commitment to the Institutes with his team, Isabelle Van Geet and Inès Tirvengadum who have managed the multiple activities flawlessly. I want to congratulate Yves Geerts for his appointment as director for Chemistry and look forward to our collaboration over the years. My special thanks go to Paul Geerlings, treasurer of the Institutes for his dedication to the sound finances of the Institutes.

**Jean-Marie Solvay | President**

## A word from the Executive Director and Director for Physics

The year 2025 marked a major change in the organization of the Solvay Institutes.

Since 2004, the number of scientific activities organized by the Institutes has grown significantly:

- The Solvay Conferences on Physics and Chemistry have resumed a regular pace of one every three years (one on physics, one on chemistry, and one "blank" year in each three-year cycle).

- The workshop program has been revitalized and its range of subjects greatly expanded.

- New programs have been established on a systematic basis:

  - Yearly public events (since 2005).

  - International Doctoral school in theoretical physics (since 2006).

  - Jacques Solvay chair in physics (since 2006).

  - Solvay chair in chemistry (since 2008).

  - New Horizons Lectures in physics and in chemistry (since 2018).

With the expansion into fundamental biology, the number of activities will increase even further.

To meet the challenges posed by these ambitious developments and to ensure the long-term sustainability of the Solvay Institutes, the Board of Directors decided to restructure the management as follows:

- One Director for Chemistry.
- One Director for Physics.
- One Executive Director ("CEO").

The last two positions are currently held by the Director for Physics.

Following the recommendation of a search committee composed of Professors Karen Goldberg (U. of Pennsylvania) and Bert Meijer (Technical U. of Eindhoven), Professor Yves Geerts (ULB) was appointed Director for Chemistry as of January 1, 2025.

The Institutes are delighted that Yves has accepted the position and are deeply grateful for his enthusiastic and skilled leadership. I would also like to commend the search committee for its rigorous work and invaluable assistance.

Another important organizational change occurred in 2026: Ms. Inès Tirvengadum joined the administrative staff as Office Manager. Thanks to her competence, eagerness to learn, and organizational skills, her integration into the team has been immediate and seamless.

On the scientific side, two events in particular stand out.

The first was the 27th Solvay Conference on Chemistry, held from 9 to 11 October 2025, and devoted to "Exploring Frontiers in Chemistry." The meeting was a great scientific success. The International Solvay Institutes extend their deepest gratitude to the conference chairs, Professors Ben Feringa and Helma Wennemers, for their outstanding work in organizing this superb event. In keeping with tradition, the chemistry meeting was followed by a public event on 12 October, addressing the conference themes.

At the start of the 27th Solvay Conference on Chemistry, the Nobel Committee announced that Professor Omar Yaghi (U. of California, Berkeley), a key participant and co-chair of the session on Chemical Complexity, had been awarded the 2025 Nobel Prize in Chemistry. Professor Yaghi previously held the 2021 Solvay Chair in Chemistry. Warmest congratulations to him once again—what an honor for the Institutes!

The second highlight of 2025 was the organization of the first Solvay Chair in Biology, held by Professor Ben Simons from Cambridge University. Professor Simons delivered a splendid inaugural lecture on "Bringing Physics to Life" and engaged fruitfully with many biology and physics groups in Belgium. A wonderful first! We are grateful to Professor Simons for making the launch of this new initiative such a success.

These two highlights are reviewed in detail in the present report, which describes all the activities organized or supported by the International Solvay Institutes during 2025. These activities covered a wide spectrum of developments at the frontiers of science. All detailed information can be found in the main body of the report.

In addition to the Institutes' activities, the report describes the research carried out by the groups of the Directors. The research highlights of other researchers connected with the Institutes are also outlined.

The Institutes would like to express their gratitude to the individuals and institutions that subsidize and support our mission: the Université Libre de Bruxelles, the Vrije Universiteit Brussel, the Syensqo company, the UCB company, the Belgian National Lottery, BNP-Paribas-Fortis, the FWO, the FRS-FNRS, the Brussels Region, the Fédération Wallonie-Bruxelles, the Solvac company, and, last but not least, the Solvay family, who continues with unwavering conviction a century-old tradition of support for fundamental research.

The Solvay family also directly supports the research of the Directors' groups. Yves and I extend our heartfelt thanks for this most precious help and trust.

Finally, I would like to warmly acknowledge the commitment and exceptional sense of responsibility of Inès Tirvengadum and Isabelle Van Geet, who have managed the logistics of our activities with remarkable efficiency and dedication.

**Marc Henneaux | Director**

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# GENERAL INFORMATION

## Board of Directors

**Jean-Marie Solvay**
President
Solvay Family
Representative

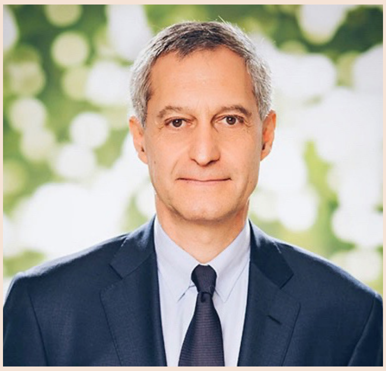
**Paul Geerlings**
Vice-President & Treasurer
VUB representative

**Annick Hubin**
Secretary
VUB representative

**Bernard De Cannière**
ULB representative

**Karsten De Clerck**
VUB representative

**Muriel De Lathouwer**
ULB representative



**Pierre Gurdjian**
ULB representative

**Edouard Janssen**
Solvay Family
Representative

**Marina Solvay**
Solvay Family
Representative

## Honorary Members

**Gino Baron**
Emeritus Professor VUB

**Franz Bingen**
Emeritus Professor VUB
Former Vice president and Treasurer of the Solvay Institutes

**Nicolas Boël**
Former Chair of the Board of the Solvay Company

**Eric Boyer de la Giroday**
Honorary Chairman of the Board of Directors of ING Belgium sa/nv

**Philippe Busquin**
Minister of State
Former European Commissioner for Research

**Eric De Keuleneer**
Former Chairman of the Board of Directors of the ULB

**Daniel Janssen**
Former Chairman of the Board of Directors of the Solvay Group

**Jean-Louis Vanherweghem**
Former Chairman of the Board of Directors of the ULB

**Lode Wyns**
Emeritus Professor VUB
Former Vice-rector for Research VUB
Former Deputy Director for Chemistry of the Solvay Institutes

## Guest Members

**Anne De Wit**
Professor ULB
Scientific Secretary of the International Committee for Chemistry

**Gert Desmet**
Professor VUB
Deputy Director for Chemistry

**Marc Henneaux**
Professor ULB
Executive Director and Director for Physics

**Yves Geerts**
Professor ULB
Director for Chemistry

**Franklin Lambert**
Emeritus Professor VUB

**Alexandre Sevrin**
Professor VUB
Deputy Director for Physics and Scientific Secretary of the International Committee for Physics

**Karel Velle**
Secretary of the Royal Flemish Academy for Science and the Arts of Belgium

**Didier Viviers**
Secretary of the Royal Academy for Science and the Arts of Belgium

## Members of the General Assembly

Antoniou Ioannis

Barnich Glenn

Baron Gino

Bingen Franz

Boël Nicolas

Boyer de la Giroday Eric

Busquin Philippe

Brouhns Alexis

Craps Ben

Croonenberghs Olivier

Damiens Antoine

Danckaert Jan

De Cannière Bernard

De Clerck Karsten

De Lathouwer Muriel

Defourny Michel

De Keuleneer Eric

De Vos Gabrielle

De Wit Anne

Desmet Gert

Englert Yvon

Gaspard Pierre

Geerlings Paul

Geerts Yves

Goldbeter Albert

Gurdjian Pierre

Halloin Véronique

Henneaux Marc

Hubin Annick

Hubinont Pascal

Janssen Daniel

Janssen Edouard

Janssen Emmanuel

Jolly Baudouin

Jourquin Christian

Lambert Franklin

Leroy Jeremie

de Maret Pierre

Mondron Edouard

Querton Alain

Querton Cédric

Rolin Patrick

Rolin Olivia

Sanglier Michèle

Schaus Annemie

de Selliers de Moranville, Jacques

Sevrin Alexandre

Madame Solvay de La Hulpe

Solvay Anne-Christine

Solvay Carole

Solvay Denis

Solvay Jean-Marie

Solvay Marina

Van Camp Benjamin

Van Gelder Eddy

Vanherweghem Jean-Louis

Van Houtte Patricia

Van Ypersele Nathalie

Velle Karel

Viviers Didier

Wielemans Patrick

Willems Hans

Willox Ralph

Wyns Lode

# Management and staff

The Directors are assisted in their scientific tasks by:

- The International Scientific Committees for Physics and Chemistry, which are fully responsible for the scientific organization of the "Conseils Solvay".
- The Executive Committee and the Local Scientific Committees, which help them with the organization of all the other activities (workshops, colloquia, chairs, new horizons lectures).

## Executive committee

Executive Director and
Director for Physics
**Professor Marc Henneaux**
ULB

**Professor Alexandre Sevrin**
VUB
Deputy Director

**Professor Glenn Barnich**
ULB

**Professor Ben Craps**
VUB

**Professor Yves Geerts**
ULB
Director for Chemistry

**Professor Gert Desmet**
VUB
Deputy Director for Chemistry

**Professor Anne De Wit**
ULB

## Administrative staff

The Directors are assisted in their management tasks by the administrative staff.

**Inès Tirvengadum**
Office Manager

**Isabelle Van Geet**
Chief Project Coordinator

**Tahar Hmida and Kevin Dubois**
Accounting Officers

# International Advisory Committee

In 2008, the Board of Directors of the International Solvay Institutes decided to set up an International Advisory Committee. The International Advisory Committee of the Solvay Institutes is composed of distinguished scientists who have the task of periodically evaluating all the scientific activities of the Solvay Institutes (outside the Solvay Conferences which are run by their own respective International Scientific Committees), make suggestions if appropriate, report to the Board of Directors and provide advice for future developments.

## Chair

**Professor Robert Dijkgraaf**
University of Amsterdam,
The Netherlands

## Members

**Professor Costas Bachas**
École Normale supérieure (ENS),
Paris, France

**Professor Leticia Cugliandolo**
Université Pierre et Marie Curie,
Paris, France

**Professor Karen I. Goldberg**
University of Pennsylvania,
Philadelphia, USA

**Professor Bert Meijer**
Eindhoven University of
Technology,
The Netherlands

**Professor Hirosi Ooguri**
California Institute of Technology,
Pasadena, USA

**Professor Gunnar von Heijne**
Stockholm University, Sweden

# International Scientific Committees

The International Scientific Committees for Physics and Chemistry are responsible for the scientific organization of the "Conseils Solvay".

They are in charge of defining the general theme of the conferences and of selecting a chair person.

## International Scientific Committee for Physics

### Chair

**Professor David Gross**
2004 Nobel Laureate
Kavli Institute for Theoretical Physics, Santa Barbara, USA

### Scientific Secretary

**Professor Alexandre Sevrin**
Vrije Universiteit Brussel, Belgium

### Members

**Professor Roger Blandford**
Stanford University, USA

**Professor Alessandra Buonanno**
Max-Planck-Institute Potsdam, Germany

**Professor Steven Chu**
1997 Nobel Laureate
Stanford University, USA

**Professor Fabiola Gianotti**
CERN, Geneva, Switzerland

**Professor Bertrand Halperin**
Harvard University, Cambridge, USA

**Professor Wolfgang Ketterle**
2001 Nobel Laureate
Massachusetts Institute of Technology, Cambridge, USA

**Professor Juan Maldacena**
IAS Princeton, USA

**Professor Giorgio Parisi**
2021 Nobel Laureate
Università La Sapienza, Roma, Italy

**Professor Peter Zoller**
University of Innsbruck, Austria

# International Scientific Committees

## International Scientific Committee for Chemistry

### Chair

**Professor Ben Feringa**
2016 Nobel Laureate
University of Groningen,
The Netherlands

### Scientific Secretary

**Professor Anne De Wit**
ULB, Brussels

### Members

**Professor Takuzo Aida**
Tokyo University, Japan

**Professor Joanna Aizenberg**
Harvard University,
Cambridge, USA

**Professor Carolyn Bertozzi**
2022 Nobel Laureate
Stanford University, USA

**Professor Thomas Ebbesen**
Strasbourg University, France

**Professor Stefan Hell**
2014 Nobel Laureate
Max-Planck-Institute,
Göttingen, Germany

**Professor David MacMillan**
2021 Nobel Laureate
Princeton University, USA

**Professor Bert Weckhuysen**
University of Utrecht,
The Netherlands

**Professor Helma Wennemers**
ETH Zurich, Switzerland

**Professor Omar Yaghi**
2025 Nobel Laureate
University of California,
Berkeley, USA

## Local Scientific Committees

The local Scientific Committees help the Directors with the organization of the Workshops, Colloquia, New Horizons Lectures, Chairs and Doctoral School.

### Local Scientific Committee for Physics

#### Chair

**Professor Marc Henneaux**
ULB, Brussels

#### Observers

**Professor Anne De Wit**
ULB, Brussels

**Professor Yves Geerts**
ULB, Brussels

#### Members

**Professor Conny Aerts**
KULeuven

**Professor Nicolas Boulanger**
UMONS

**Professor Giacomo Bruno**
UCLouvain

**Professor Ben Craps**
VUB, Brussels

**Professor Jean-René Cudell**
ULiège

**Professor Sophie de Buyl**
VUB, Brussels

**Professor Pierre Gaspard**
ULB, Brussels

**Professor Michael Gillon**
ULiège

**Professor Joseph Indekeu**
KULeuven

**Professor Philippe Lambin**
FUNDP, Namur

**Professor Jean Manca**
UHasselt

**Professor Dirk Ryckbosch**
UGent

**Professor Alexandre Sevrin**
VUB, Brussels

**Professor Jacques Tempere**
UAntwerp

**Professor Petr Tinyakov**
ULB, Brussels

**Professor Sophie Van Eck**
ULB, Brussels

**Professor Frank Verstraete**
UGent

# Local Scientific Committees

## Local Scientific Committee for Chemistry

### Chair

**Professor Yves Geerts**
ULB, Brussels

### Observers

**Professor Marc Henneaux**
ULB, Brussels

**Professor Pierre Gaspard**
ULB, Brussels

### Members

**Professor Mercedes Alonso Giner**
VUB, Brussels

**Professor Annemie Bogaerts**
UAntwerp

**Professor Benoît Champagne**
FUNDP, Namur

**Professor Jérôme Cornil**
UMONS

**Professor Frank De Proft**
VUB, Brussels

**Professor Anne De Wit**
ULB, Brussels

**Professor Gert Desmet**
VUB, Brussels

**Professor Jeremy Harvey**
KULeuven

**Professor Sophie Hermans**
UCLouvain

**Professor Luc Moens**
UGent

**Professor Jean-Christophe M. Monbaliu**
ULiège

**Professor Han Remaut**
VUB, Brussels

**Professor Hennie Valkenier**
ULB, Brussels

**Professor Marlies Van Bael**
UHasselt

**Professor Veronique Van Speybroeck**
UGent

**Professor Lode Wyns**
VUB, Brussels

## Honorary members

**Professor Claudio Bunster**
Centro de Estudios Científicos,
Valdivia, Chile

**Professor Thomas Cech**
1989 Nobel Laureate
University of Boulder, Colorado,USA

**Professor Claude Cohen-Tannoudji**
1997 Nobel Laureate
École Normale Supérieure, Paris, France

**Professor Robbert Dijkgraaf**
President-Elect of the International
Science Council

**Professor François Englert**
2013 Nobel Laureate
ULB, Belgium

**Professor Gerhard Ertl**
2007 Nobel Laureate
Fritz-Haber-Institut der
Max-Planck-Gesellschaft Berlin, Germany

**Professor Graham Fleming**
University of Berkeley, USA

**Professor Gerard 't Hooft**
1999 Nobel Laureate
Spinoza Instituut, Utrecht,
The Netherlands

**Christian Jourquin**
Former CEO Solvay Group,
Belgium

**Professor Roger Kornberg**
2006 Nobel Laureate
Stanford University, USA

# Honorary members

**Professor Jean-Marie Lehn**
1987 Nobel Laureate
Collège de France, Paris, France

**Professor Henk N.W. Lekkerkerker**
Utrecht Universiteit
The Netherlands

**Professor Hermann Nicolai**
Max-Planck-Institut für
Gravitationsphysik, Golm,
Germany

**Professor Kyriacos Costa Nicolaou**
University of California, San Diego,
USA

**Professor Jacques Prost**
Institut Curie, Paris, France

**Professor Pierre Ramond**
University of Florida, Gainesville,
USA

**Professor Victor A. Sadovnichy**
Moscow State University, Russia

**Professor Roald Sagdeev**
University of Maryland, College
Park, USA

**Madame Solvay de la Hulpe**
Belgium

**Professor JoAnne Stubbe**
Massachusetts Institute of
Technology, USA

**Professor Irina Veretennicoff**
Emeritus Professor VUB, Belgium

**Professor Klaus von Klitzing**
1985 Nobel Laureate
Max-Planck-Institut, Stuttgart,
Germany

**Professor George M. Whitesides**
Harvard University, USA

**Professor Kurt Wüthrich**
2002 Nobel Laureate
Scripps Research Institute,
La Jolla, USA and ETH Zurich,
Switzerland

## In memoriam

The International Solvay Institutes mourn the passing away of Professor Chen Ning Yang on 18 October 2025.

Professor Yang is well known for his outstanding contributions to theoretical physics. He was awarded the Nobel Prize in 1957 (at the exceptionally young age of 35) with T.D. Lee "for their penetrating investigation of the so-called parity laws which has led to important discoveries regarding the elementary particles". He visited the Institutes various times, where he gave beautiful lectures. He was one of our distinguished honorary members.

The Institutes will deeply miss him.

02

# 27th SOLVAY CONFERENCE ON CHEMISTRY

# 27$^{th}$ Solvay Conference on Chemistry "Exploring Frontiers in Chemistry"

9 - 11 October 2025

## Organising Committee

### Chair

**Ben Feringa**
2016 Nobel Laureate
University of Groningen,
The Netherlands

### Vice-chair

**Helma Wennemers**
ETH Zurich, Switzerland

## 27$^{th}$ Solvay Conference

By a happy coincidence, the 27$^{th}$ Solvay Conference on Chemistry began on the very day the 2025 Nobel Prizes in Chemistry were announced. Participants were overjoyed to learn that one of their own, Omar Yaghi, a professor at the University of Berkeley, had been awarded the prize "for the development of metal-organic frameworks". This most fortunate event helped to foster a spirit of emulation particularly conducive to scientific discussion.

Chemistry is a multifaceted discipline with developments in diverse fields. Ben Feringa, winner of the 2016 Nobel Prize in Chemistry, and Helma Wennemers, Professor at ETH Zurich, who jointly chaired the 27$^{th}$ Solvay Conference on Chemistry, aptly chose, in close collaboration with the International Committee on Chemistry, the overarching and unifying theme "Exploring Frontiers in Chemistry" to cover the most innovative and unexplored aspects of modern chemistry. The conference comprised six half-day sessions. Chemists, biochemists, and physicists, including four Nobel laureates in Chemistry, from a wide range of backgrounds, briefly presented their latest findings, focusing on unresolved questions and major challenges to stimulate discussion. Ernest Solvay's quote, "There is no limit to what science can explore", was once again proven true. Automation and robotics, artificial intelligence, new synthetic methods, lattice chemistry, the chemistry-biology interface, chemistry in confinement, the dynamics of chemical systems, and the coupling of molecular electronic states with the quantized states of the vacuum were discussed.

The conference took place at the Plaza Hotel from Thursday 9 October to Saturday, October 11, 2025. The Solvay Institutes thank the chairs, participants, attendees, and organizers for making this conference a resounding success, the impact of which will be measured by numerous future developments. The assistance and support of Syensqo are also particularly appreciated.

## Scientific Background

Chemistry is a natural science that studies the composition of matter and its transformations, more specifically atoms, through their assemblies called molecules, the chemical reactions that change these molecules while preserving the atoms, producing or not producing heat or light, and the forces that promote or hinder these chemical reactions.

Chemical phenomena occur at different time scales and lengths, often in a complex and hierarchical manner. Beyond this inherent complexity, it is important to emphasize the extreme diversity of chemical phenomena, which are found in both industrial and natural processes. Another important characteristic of chemical phenomena is that they are not always predictable from first principles. Phil Anderson, winner of the 1977 Nobel Prize in Physics, perfectly summarized this fact: *"The ability to reduce everything to simple fundamental law does not imply the ability to start from those laws and reconstruct the universe."*

Currently, chemical research is progressing in a multitude of fields that exhibit both similarities and differences. Rationalizing the results into knowledge constructed and supported by a robust theoretical framework is a major challenge that could be met by artificial intelligence. In the hands of skilled and critical scientists, AI is a fantastic tool for data analysis. But chemistry is not limited to observing and understanding chemical phenomena; it is also eminently creative, as chemists are now able to synthesize virtually any molecule and assemble them into supramolecular architectures of ever more complex and functional size, shape, and structure. The 27th Solvay Conference on Chemistry embraced with enthusiasm and curiosity the diversity, complexity, and beauty of chemical phenomena in order to contribute to the advancement of science and the well-being of humanity.

# 27th Solvay Conference on Chemistry "Exploring Frontiers in Chemistry"

## Programme

### 9 October 2025

Welcome addresses by Marc Henneaux and Yves Geerts

Opening Session by Ben Feringa

*Session 1: Chemical Complexity: From Materials to Complex Order*
Chairs: Takuzo Aida and Omar Yaghi

*Session 2: Emerging Methodology: Sustainable Synthesis & Photoredox Catalysis*
Chair: David MacMillan

### 10 October 2025

*Session 3: Exploring the Chemistry–Biology Interface*
Chair: Helma Wennemers

*Session 4: The Lab of the Future: AI, Robotics, Automation*
Chairs: Andy Cooper and Frank Glorius

### 11 October 2025

*Session 5: Chemistry in Confined Space*
Chairs: Joanna Aizenberg and Thomas Ebbesen

*Session 6: Dynamic Chemical Systems*
Chairs: Andy Cooper and Frank Glorius

## Participants

**Takuzo Aida**
University of Tokyo, Japan

**Joanna Aizenberg**
Harvard University, USA

**Thorsten Bach**
Technical University Munich, Germany

**Shankar Balasubramanian**
University of Cambridge, UK

**Emily Balskus**
Harvard University, USA

**Peng Chen**
Cornell University, USA

**Jacqui Cole**
University of Cambridge, UK

**Andy Cooper**
University of Liverpool, UK

**Anne De Wit**
ULB, Brussels, Belgium

**Thomas Ebbesen**
Université de Strasbourg, France

**Ben Feringa**
University of Groningen, The Netherlands

**Dorothea Fiedler**
Leibniz-Forschungsinstitut für Molekulare, Germany

**Matt Gaunt**
University of Cambridge, UK

**Yves Geerts**
ULB, Brussels, Belgium

**Arne Gennerich**
Albert Einstein Coll. of Medicine, USA

**Frank Glorius**
University of Münster, Germany

**Karen Goldberg**
University of Pennsylvania, USA

**Andrew Goodwin**
Oxford U., UK

**Stefan Hell**
Max Planck Institute, Germany

**Patricia Horcajada**
IMDEA Energy Institute, Madrid, Spain

**Todd Hyster**
Princeton University, USA

**Kim Jelf**
Imperial College London, UK

**Klavs Jensen**
MIT, USA

**Bettina V. Lotsch**
Max Planck Institute, Germany

**David MacMillan**
Princeton University, USA

**Stephen Mann**
University of Bristol, UK

**Jim McCusker**
Michigan State University, USA

**Bert Meijer**
Eindhoven University of Technology, The Netherlands

**Beatriz Roldan**
Fritz Haber Institute of the Max Planck Society, Germany

## 27th Solvay Conference on Chemistry "Exploring Frontiers in Chemistry"

### Participants

**Angel Rubio**
Max Planck Institute, Germany

**Franziska Schoenebeck**
RWTH Aachen U, Germany

**Peter Seeberger**
Max Planck Institute, Germany

**Berend Smit**
EPFL, Lausanne, Switzerland

**Felix Strieth-Kalthoff**
University of Wuppertal, Germany

**Hiroaki Suga**
University of Tokyo, Japan

**Akif Tezcan**
University of California, San Diego, USA

**Anoop Thomas**
Indian Institute of Science, Bengaluru, India

**Hennie Valkenier-van Dijk**
ULB, Brussels, Belgium

**Gunnar von Heijne**
Stockholm University, Sweden

**Bert Weckhuysen**
Universiteit Utrecht, The Netherlands

**Helma Wennemers**
ETH Zürich, Switzerland

**Omar Yaghi**
University of California, Berkeley, USA

**Vivian Yam**
University of Hong Kong

**Peidong Yang**
University of California, Berkeley, USA

**Ahmet Yildiz**
University of California, Berkeley, USA

**Lauren Zarzar**
Penn State University, USA

**Zhiwei Zuo**
Shanghai Institute of Organic Chemistry, China

## Auditors

**Carmela Aprile**
(UNamur, Belgium)

**Cédric Theunissen**
(ULB, Belgium)

**Chloé Martens**
(ULB, Belgium)

**Françoise Remacle**
(ULiège, Belgium)

**Han Remaut**
(VUB, Belgium)

**Jeremy Harvey**
(KU Leuven, Belgium)

**Ludovic Troian-Gautier**
(UCLouvain, Belgium)

**Mercedes Alonso-Giner**
(VUB, Belgium)

**Sara Bals**
(UAntwerpen, Belgium)

**Véronique Van Speybroeck**
(UGent, Belgium)

**Yannick De Decker**
(ULB, Belgium)

**Yoann Olivier**
(UNamur, Belgium)

Unofficial photo taken with Prof. Omar Yaghi before his departure, as he was understandably unable to stay for the full conference after winning the Nobel Prize on the same day.

03

# OUTREACH ACTIVITIES

# Solvay Public Lectures

## 23rd Solvay Public Event – 12 October 2025

## "Exploring Frontiers in Chemistry"

In 2005, the International Solvay Institutes initiated the tradition of organizing an annual public event during which distinguished scientists deliver lectures on the state-of-the-art in their field of research with an overview of the most pressing current issues. Organized jointly with the ULB, the VUB and the Syensqo Company, this event popularizes science and aims at making it more attractive to the younger generations. The talks are given in English but simultaneous interpretations in Dutch and French are provided. The event closes with a drink offered to all the participants, which allows the public to interact more closely with the invited scientists. The event is free.

The list of all our public events is given at the end of this report.

On the day following the 27th Solvay Conference on Chemistry, the International Solvay Institutes organized their traditional annual public event, the aim of which was to provide a broad, state-of-the-art view on the central scientific themes of the conference.

The event was preceded by a short Syensqo award ceremony. The program continued with two lectures for the general public, followed by a panel debate addressing questions raised by the audience. The event closed with a drink offered to all the participants, during which the public could interact with the speakers and the panel members.

The public lectures were delivered by two of the leading world experts in chemistry. Professor Helma Wennemers (ETH Zurich, Switzerland) gave a splendid lecture on "Peptides – Molecular Allrounders", explaining the great variety and versatility of these polymers made out of amino acids, which have many remarkable applications.

In his fascinating lecture "Reading your DNA: What does it tell us?", Professor Shankar Balasubramanian (University of Cambridge, UK) described how new revolutionary techniques can t decode and interpre our DNA in record time, with spectacular impact in many areas of medicine. Professor Helma Wennemers also chaired with brio the panel debate that followed.

Both lectures captivated the audience which filled, as usual, the Studio 4 of Flagey. The international Solvay Institutes are most grateful to the lecturers and the panelists for their active involvement in the success of the event.

## Programme

**Moderator**
Alexandre Sevrin
VUB & International Solvay Institutes

**Opening by**
Marc Henneaux and Yves Geerts
ULB & International Solvay Institutes

**ULB / VUB Syensqo Awards Ceremony***
Thomas Canova
R&I Director, Syensqo

**Lectures**
"Peptides – Molecular Allrounders"
Helma Wennemers
ETH, Zurich

"Reading your DNA: What does it tell us?"
Shankar Balasubramanian
University of Cambridge

**Panel Discussion**

Helma Wennemers (Chair)
ETH, Zurich

Shankar Balasubramanian
University of Cambridge

Jacqui Cole
University of Cambridge

Dorothea Fiedler
FMP, Berlin

Bettina Lotsch
MPI, Stuttgart

Berend Smit
EPFL, Lausanne

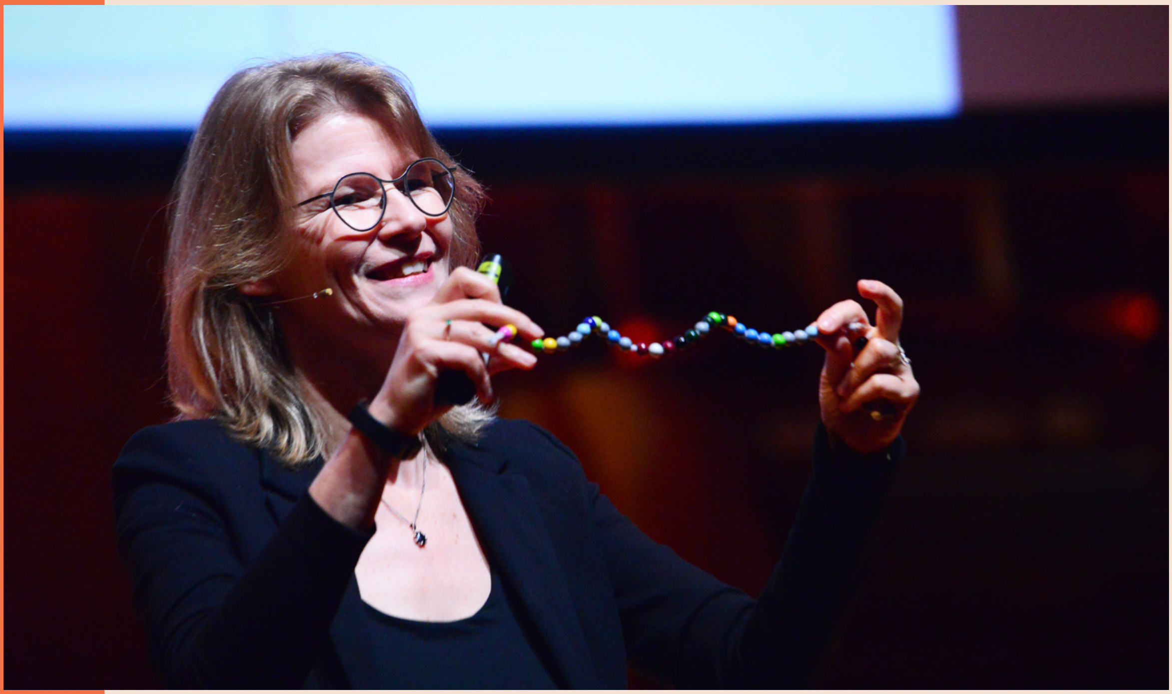
**Closing**
Marc Henneaux and Yves Geerts
ULB & International Solvay Institutes

### *Syensqo Awards Ceremony

One of the goals of the Solvay public event is to stimulate interest for science and scientific research, especially among the young generations. In that spirit, the event started with a Syensqo award ceremony. The ceremony celebrated students in physics, chemistry and engineering at the ULB and the VUB who had been distinguished for their work. These Syensqo awards are given by the Syensqo Company.

## Lectures

### Helma Wennemers (Chair)
ETH, Zürich



Helma B. Wennemers is a chemist specializing in organic and peptide chemistry. She is a professor of organic chemistry at the Swiss Federal Institute of Technology in Zurich (ETH Zurich).

Helma Wennemers studied chemistry at the University of Frankfurt, where she obtained a degree in chemical sciences with Gehrhard Quinkert in 1993. From 1993 to 1996, she completed her doctoral thesis in the group of W. Clark Still at Columbia University in New York. She then joined the laboratory of Hisashi Yamamoto at Nagoya University for a postdoctoral stay.

In 1999, she accepted a position as assistant professor at the University of Basel and, in 2003, she was appointed associate professor at the same university. In 2011, she was promoted to full professor of organic chemistry at ETH Zurich.

Helma Wennemers' scientific research focuses on organic chemistry, drawing inspiration from biological systems with an emphasis on proline-rich peptides or proteins. Her work has led to applications in the detection and treatment of cancer.

Her discoveries earned her the Pedler Award from the Royal Society of Chemistry in 2016. She is the first woman, as well as the second Swiss scientist, to receive this distinction.

## Shankar Balasubramanian
University of Cambridge

Sir Shankar Balasubramanian is the Herchel Smith Professor of Medicinal Chemistry at the University of Cambridge and senior group leader at Cancer Research UK's Cambridge Institute.

Professor Balasubramanian completed his BA in Natural Sciences (1988) and PhD in enzyme Chemistry (1991) both at the University of Cambridge. He was a NATO fellow at the Pennsylvania State University (1992-93), then joined the faculty at the University of Cambridge in 1994.

Sir Balasubramanian was knighted in the Queen's New Year's Honours in 2017. He was awarded the Royal Medal in 2018 jointly with David Klenerman, the 2020 Millennium Technology Prize jointly with David Klenerman, and the 2022 Breakthrough Prize for Life Sciences jointly with David Klenerman and Pascal Mayer.

He is an elected Fellow of the Royal Society of London (2012), the Academy of Medical Sciences (2011), a member of EMBO (2012), Academia Europaea (2023) and a Foreign Associate of the National Academy of Sciences (2023).

## Solvay Public Lectures

### Panel Members

**Jacqueline Cole**
University of Cambridge


Jacqueline Cole holds the Royal Academy of Engineering Research Professorship in Materials Physics at the University of Cambridge, where she is Head of Molecular Engineering. She combines artificial intelligence with data science, computational methods and experimental research to afford a 'design-to-device' pipeline for data-driven materials discovery. Her research is highly interdisciplinary. Accordingly, she holds two PhDs: one in Physics from the University of Cambridge and one in Chemistry from the University of Durham.

She has received a number of awards and honours including: the Royal Society Clifford Paterson Medal and Lecture 2020; the BASF / Royal Academy of Engineering Research Chair and Senior Research Fellowship in Data-driven Molecular Engineering of Functional Materials (2018-2023); the 1851 Royal Commission 2014 Fellowship in Design (2015-8), a Fulbright Award (all disciplines Scholar, 2013-4), and an ICAM Senior Scientist Fellowship (2013-4) for the smart material design of dye-sensitized solar cells.

**Dorothea Fiedler**
FMP, Berlin


Dorothea Fiedler is a German chemical biologist and Professor of Chemical Biology at Humboldt University of Berlin and Director at the Leibniz Research Institute for Molecular Pharmacology (FMP) in Berlin. Her research investigates the chemical basis of cellular signaling and metabolism, with a particular focus on inositol polyphosphates and related small molecules that regulate key biological processes.

Professor Fiedler studied chemistry at the University of Würzburg and earned her PhD at the University of California, Berkeley. After postdoctoral research at the University of California, San Francisco, she began her independent career as an Assistant Professor at Princeton University. In 2015, she moved to Berlin to lead her research group at FMP.

Her work has been recognized with several awards, including the NIH Director's New Innovator Award, the Rita Allen Foundation Scholar Award, and the Sidney Kimmel Scholar Award.

## Bettina V. Lotsch
MPI, Stuttgart

Bettina V. Lotsch is Director at the Max Planck Institute for Solid State Research in Stuttgart and Professor of Inorganic Solid-State Chemistry at Ludwig-Maximilians-Universität München. Her research focuses on the design and synthesis of functional inorganic materials, with particular emphasis on two-dimensional solids, porous frameworks, and photocatalysts for solar energy conversion and sustainable chemical transformations.

After studying chemistry at LMU Munich, where she received her PhD in 2006, she conducted postdoctoral research at the University of Toronto before returning to Germany. She is the recipient of several prestigious awards, including the Gottfried Wilhelm Leibniz Prize (2025), the EU-40 Materials Prize (2017), and an ERC Starting Grant (2014). Her work aims to understand how the structure and composition of solids determine their properties, enabling the development of new materials for energy, catalysis, and sensing applications.

## Berend Smit
EPFL, Lausanne

Berend Smit is a Professor in the School of Basic Sciences at EPFL and a leading researcher in computational chemistry and materials science. His work focuses on the molecular simulation and data-driven design of functional materials, particularly nanoporous materials such as zeolites and metal–organic frameworks, with applications in energy, separations, and catalysis.

He studied chemical engineering at Delft University of Technology and earned his PhD at Utrecht University. Over the course of his career, he has held academic positions in the Netherlands and the United States before joining EPFL. He is widely recognized for pioneering contributions to molecular simulation, statistical thermodynamics, and the computational discovery of porous materials.

# 04

# SCIENTIFIC ACTIVITIES

# International Solvay Chairs

The International Solvay Chair programme enables the Institutes to invite eminent scientists to Brussels for a period of one to two months in order to give lectures on their work to researchers in the corresponding fields, not only from the ULB and the VUB, but also from other Belgian universities and abroad.

The programme started in 2006 for physics. In 2011, the physics chair was renamed the International "Jacques Solvay Chair in Physics" in memory of Jacques Solvay, who was president of the Institutes for more than 50 years.

The chair programme in chemistry began in 2008 thanks to a generous grant from the Solvay Company. This key support was taken over in 2024 by the Syensqo Company for two years (2024 and 2025), during which the Chemistry Chair was renamed "Syensqo Chair in Chemistry by the International Solvay Institutes".

The new chair programme in biology was launched in 2025 thanks to the generosity of the Solvay family and the UCB company. It illustrates the desire of the Solvay family and the Solvay Institutes to expand towards life sciences. The initial success of this initiative will lead to its renewal on the same annual basis as the two other chair programmes.

## 2025 Syensqo Chair in Chemistry by the International Solvay Institutes


### Laura Gagliardi
The University of Chicago, USA

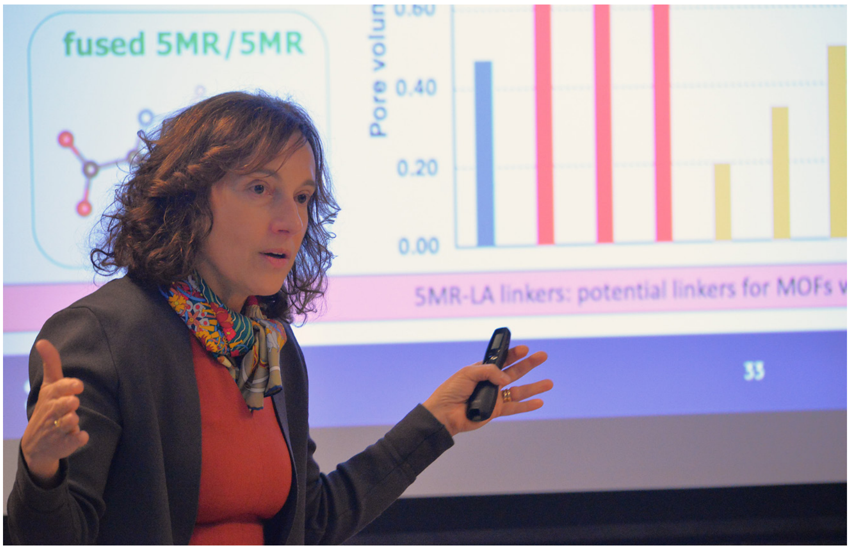

The 2025 Solvay Chemistry Chair by Syensqo was awarded to Laura Gagliardi, who is a theoretical and computational chemist.

She received a Master's degree and a PhD in chemistry from the University of Bologna. Then, she was awarded a postdoctoral fellowship at the University of Cambridge. She was a professor at the University of Geneva, and the University of Minnesota before joining the University of Chicago in 2020 as professor of chemistry and molecular engineering.

Her research focuses on:

i) the electronic structure of molecules,
ii) catalysis and materials for energy,
iii) $CO_2$ separation, and
iv) the chemistry of heavy elements (actinides).

She has received several prestigious awards, for example: the Peter Debye Award from the American Chemical Society, the Humboldt Research Award, and the Bourke Award from the Royal Society of Chemistry. She is also a member of major scientific academies, including the National Academy of Sciences in the United States. The Solvay Institutes are greatly honoured that she accepted the invitation to share her knowledge on advanced quantum calculation methods.



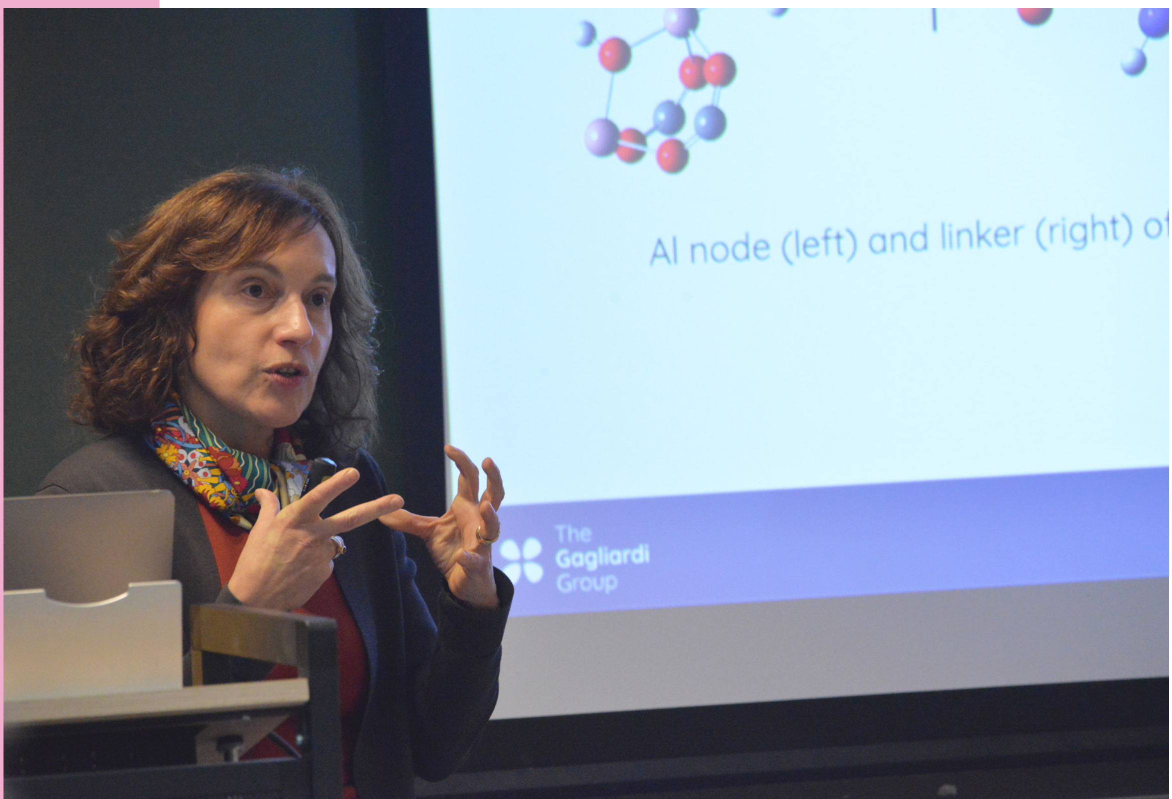
## 2025 Syensqo Chair in Chemistry by the International Solvay Institutes

### Programme

Professor Gagliardi visited several times between January and October 2025. She was hosted by the Director of the International Solvay Institutes for Chemistry, Yves Geerts, who played a central role in the scientific organization of the chair.

Professor Gagliardi's inaugural lecture, delivered on January 28, addressed the synergies between theory, computation, and machine intelligence to accelerate the discovery of innovative reticular materials, with particular emphasis on their applications in catalysis and water harvesting.

The inaugural lecture was followed by three additional, more specialized lectures.



## Inaugural Lecture
28 January 2025

*"Theory, Computation and Machine Intelligence for Reticular Chemistry"*

I will describe the synergies of theory, computation, and machine intelligence to expedite the discovery of innovative reticular materials, with a particular focus on their application in catalysis and water harvesting.

I will first discuss our current endeavors in understanding and optimizing the water-harvesting potential of metal-organic frameworks (MOFs) and covalent organic frameworks (COFs) by the elucidation of the water-filling mechanism.[1], [2]

I will then present a comprehensive computational and data-driven investigation, complemented by experimental work, focusing on sulfur-based MOFs for electrocatalytic transformations relevant to hydrogenation and $CO_2$ reduction.[3]

The computational insights have played a pivotal role in guiding the synthesis of novel MOFs. Initiating our study with previously reported Fe4S4 chain coordination polymers, we systematically explore the influence of alternative linkers and counter-cations on the material's structure. This investigation aims to tailor these materials into porous 2D or 3D frameworks. Notably, our efforts have resulted in the development of a computational workflow for MOF and COF structure prediction.[4]

[1] N. Hanikel, D. Kurandina, S. Chheda, Z. Zheng, Z. Rong, S. E. Neumann, J. Sauer, J. I. Siepmann, L. Gagliardi, and O. M. Yaghi, MOF Linker Extension Strategy for Enhanced Atmospheric Water Harvesting, ACS Central Science., 2023, 9, 551–557, DOI: 10.1021/acscentsci.3c00018.

[2] D. Kurandina, B. Huang, W. Xu, N. Hanikel, A. Darù, G.D. Stroscio, K. Wang, L. Gagliardi, F.D. Toste, O.M. Yaghi, A Porous Crystalline Nitrone-Linked Covalent Organic Framework, A. C. Int. Ed. 2023, 62, e202307674 DOI: 10.1002/anie.202307674

[3] N. Jiang, A. Darù, Š. Kunstelj, J. G. Vitillo, M.E. Czaikowski, A. Wuttig, L. Gagliardi, J.S. Anderson, Catalytic, Spectroscopic, and Theoretical Studies of Fe4S4-Based Coordination Polymers as Heterogeneous CPET Mediators for Electrocatalysis J. Am. Chem. Soc., 2024, 146, 12243–12252. DOI: 10.1021/jacs.4c03726

[4] A. Darù, J. Anderson, D. Proserpio, and L. Gagliardi, Symmetry is the Key to the Design of Reticular Frameworks, ChemRxiv, 2024. DOI: 10.26434/chemrxiv-2024-37wks.

# 2025 Syensqo Chair in Chemistry by the International Solvay Institutes

## Lecture at ULB

18 February 2025

*"A Journey with Strong Electron Correlation"*

Quantum chemistry calculations of large, strongly correlated systems based on multireference wave functions are typically limited by the computation cost that scales exponentially with the size of the complete active space (CAS) used to describe the phenomena of interest. I will describe advancements in electronic structure theory, focusing on the exploration of multimetallic molecular systems characterized by strong electron correlation. The localized active space self-consistent field (LASSCF) method provides a practical alternative to CAS approaches by factorizing the wave function into localized fragments, with inter-fragment correlation reintroduced via LAS state interaction (LASSI).[1]

However, optimal strategies for defining LAS fragments and LASSI model spaces remain an open challenge. I will present our latest efforts to automate LASSI and its application to multimetallic complexes.[2] Finally, I will discuss post-CASSCF methods such as multiconfiguration pair-density functional theory (MC-PDFT)[3],[4] which provide an efficient way to recover electronic correlation outside the active space.


[1] M. R. Hermes, R. Pandharkar. L. Gagliardi, Variational Localized Active Space Self-Consistent Field Method, J. Chem. Theory Comput. 2020, 16, 4923–4937.

[2] V. Agarwal, D. S. King, M. R. Hermes, L. Gagliardi, Automatic State Interaction with Large Localized Active Spaces for Multimetallic Systems, J. Chem. Theory Comput., 2024, 20, 4654-4662.

[3] M. Hennefarth, M. Hermes, D. Truhlar, L. Gagliardi, Linearized Pair-Density Functional Theory, J. Chem. Theory Comput., 2023, 19, 3172–3183.

[4] J. Bao, D. Zhang, S. Zhang, L. Gagliardi, D. Truhlar, A Hybrid Meta On-Top Functional for Multiconfiguration Pair-Density Functional Theory, PNAS, 2025, 122,. e2419413121.

## Lecture at ULB

2 September 2025

*"Multireference Electronic Structure and Machine Learning for Reactivity and Excited States"*

Multireference electronic structure methods are indispensable for accurately describing systems with strong multiconfigurational character, yet their high computational cost and reliance on manual active-space selection limit widespread application. These constraints preclude black-box usage and the creation of large, systematic datasets. To address these challenges, we have developed automated multireference workflows to generate extensive datasets for excitation energies[1] and reactivity[2].

To extend these methods to reactive dynamics, we constructed machine learning potentials (MLPs) trained on multireference data. A key difficulty is the sensitivity of multireference results to active-space choices across diverse geometries. We resolved this by introducing the weighted active space protocol (WASP)[3], a systematic strategy for consistent active-space assignment across nuclear ensembles. Integrating WASP with MLPs and enhanced sampling yields a data-efficient active learning framework that produces robust, multireference-quality MLPs. We demonstrate this approach on $TiC^{+}$-catalyzed methane C–H activation, a reaction inaccessible to conventional density functional theory due to its strong multireference character.


[1] J. J. Wardzala, D. S. King, and L. Gagliardi, J. Phys. Chem. A, 2025, 129, 2683–2691.

[2] J. J. Wardzala, D.S. King, L. Ogunfowora, B. Savoie, and L. Gagliardi, ACS Cent. Sci, 2024, 10, 833–841.

[3] A. Seal, S. Perego, M. R. Hennefarth, U. Raucci, L. Bonati, M. Parrinello, L. Gagliardi 2025 https://doi.org/10.48550/arXiv.2505.10505.

# 2025 Syensqo Chair in Chemistry by the International Solvay Institutes

## Lecture at ULB

21 October 2025

*"Reticular frameworks after the Nobel prize: their application for catalysis and $CO_2$ capture"*

Following reflection on the 2025 Nobel Prize in Chemistry awarded for advances in metal–organic frameworks (MOFs), this lecture explores how state-of-the-art quantum chemical and classical simulations are driving the discovery of reticular materials. Computation today is not only a tool to rationalize experiments, but increasingly a predictive engine for tailoring functional frameworks.

In the first part of the presentation, I will highlight our integrated computational and experimental study of catalytic MOFs, where post-synthetic modification introduced metal–sulfur active sites[1]. Quantum chemical calculations elucidated how sulfur incorporation modulates the electronic structure and catalytic reactivity of the frameworks. These insights provided a mechanistic understanding of hydrogenation catalysis and guided the design of MOFs with tunable properties.

The second part will focus on covalent organic frameworks (COFs). Thanks to their modular architectures and tunable functionalities, COFs offer a highly versatile platform for $CO_2$ direct air capture. We performed a multiscale investigation of COF-999 and its amine-functionalized precursor COF-999-$NH_2$, integrating density functional theory, molecular dynamics, and grand canonical Monte Carlo simulations with experimental validation[2]. Our findings highlight subtle energy differences in laterally shifted stackings, intrinsic stacking heterogeneity, and pronounced layer buckling.

We found that extensive amine–nitrile hydrogen bonding and persistent pore water lead to undesired polymerization that undermines $CO_2$ uptake. The predicted presence of water is confirmed by subsequent experiments. These insights point to a single, actionable design rule: exclude retained water by introducing hydrophobic pore environments to maximize $CO_2$ capture efficiency.

[1] H. Xie, M. A. Khoshooei, M. Mandal, S. M. Vornholt, J. Hofmann, L. M. Tufaro, K. O. Kirlikovali, D. A. Grimes, S. Lee, S. Su, S. Reischauer, D. Sengupta, K. Fahy, K. Ma, X. Wang, F. Sha, W. Gong, Y. Che, J. G. Vitillo, J. S. Anderson, J. M. Notestein, K. W. Chapman, L. Gagliardi, and O. K. Farha, Introducing Metal–Sulfur Active Sites in Metal–Organic Frameworks Via Post-Synthetic Modification for Hydrogenation Catalysis, Nature Chemistry, 2025. DOI:10.1038/s41557-025-01876-y

[2] H. Daglar, Z. Zhou, R. Zhu, P. Parihar, J. I. Siepmann, O. M. Yaghi, L. Gagliardi Discovery of Stacking Heterogeneity, Layer Buckling, and Residual Water in COF-999-$NH_2$ and Implications on $CO_2$ Capture, submitted (2025)

## Other Lectures and visits

**29 January** – VUB

**19 February** – UMONS

**20 February** – Syensqo

**21 February** – UGent

**3 September** – Eindhoven University of Technology

**22 October** – UNamur

**23 October** – ULiège

**24 October** – KU Leuven

## 2025 Jacques Solvay International Chair in Physics


### Vyacheslav Rychkov
Institut des Hautes Etudes Scientifiques, Bures-sur-Yvette, France


The 2025 International Jacques Solvay Chair in Physics was held by Professor Vyacheslav Rychkov from the Institut des Hautes Études Scientifiques (IHES) in Bures-sur-Yvette (France).

Slava Rychkov is a leading figure in quantum field theory and high-energy physics. His past work covers a wide range of subjects from pure mathematics to particle physics and string theory. For his pioneering contributions to conformal field theory, he received in 2014 the New Horizons in Physics Prize "for developing new techniques in conformal field theory, reviving the conformal bootstrap program for constraining the spectrum of operators and the structure constants in 3D and 4D CFTs."

His inaugural lecture, given on March 25, 2025, was entitled "The renaissance of axiomatic methods in quantum field theory" and described in a very lucid way the bootstrap methods and some of their applications in the study of critical phenomena and scattering processes. These methods provide efficient techniques for the major challenge of solving strongly coupled quantum field theories.

The programme of Professor Rychkov's chair also involved an advanced course at the doctoral level as well as specialized lectures at the frontiers of his research, in Brussels, Ghent and Leuven.

The International Solvay Institutes are grateful to Professor Rychkov who accepted the 2025 Jacques Solvay Chair.

Slava Rychkov studied physics in Moscow, where he obtained his diploma from the Moscow Institute of Physics and Technology. He received then his PhD degree in mathematics from Princeton University, in 2002, with Alexander Polyakov as his (unofficial) supervisor.

After post-doctoral positions at the University of Amsterdam and at the Scuola Normale Superiore in Pisa, he successively became assistant professor in Pisa in 2007 and then professor of physics at the University of Paris VI in 2009, as well as member of the Laboratory of Theoretical Physics at the École Normale Supérieure in Paris. From 2012 to 2017 he was a staff member of the Department of Theoretical Physics at CERN. He was appointed Mitsubishi Heavy Industries professor of High-Energy Physics at the École Normale Supérieure in Paris in 2016 and in 2017 he got the very prestigious position of permanent professor at the Institut des Hautes Études Scientifiques.

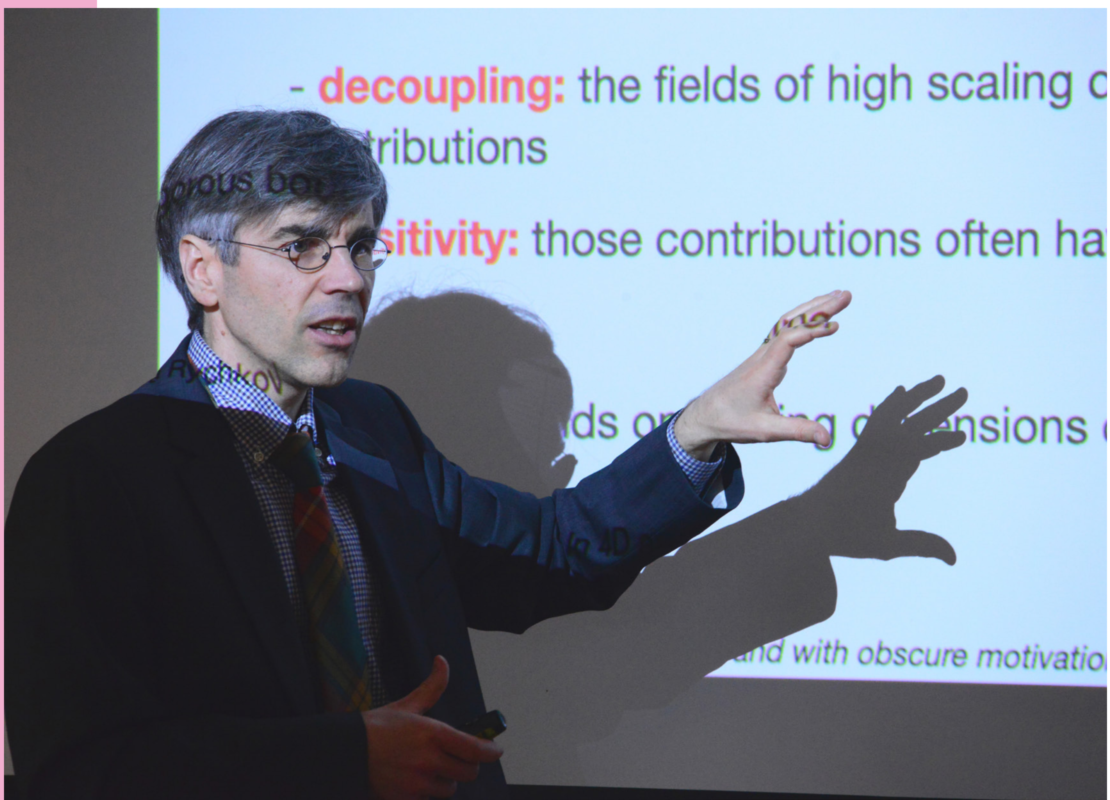
For his pioneering contributions to conformal field theory, he received in 2014 the New Horizons in Physics Prize as well as the 2019 Grand Prix Mergier-Bourdeix of the French Academy of Sciences.

## 2025 Jacques Solvay International Chair in Physics

### Inaugural lecture
25 March 2025

*"The renaissance of axiomatic methods in quantum field theory"*

The textbook approach to quantum field theory is to start from the Lagrangian and then either do perturbation theory or, if the theory is strongly coupled, resort to lattice Monte Carlo simulations. Recently, there has been renewed interest in developing and applying "bootstrap methods", which have different spirit. They use nonperturbatively valid "axioms" to obtain concrete numerical results about experimentally relevant strongly coupled QFTs. I will describe these bootstrap methods and some of their applications in the study of critical phenomena and scattering processes.



## Lectures at ULB

Tuesday 15 April
Wednesday 16 April
Thursday 17 April

***"Analyticity in Quantum Field Theory"***
3-days course

Analyticity of observables plays a major role in the S-matrix bootstrap. This blackboard course revisited the basic notions and classic results of analyticity, according to the following plan:

Analyticity in position space.
Edge-of-the-wedge theorem.
Analyticity in momentum space.
Generalized retarded functions.
Steinmann sphere.
Crossing.
Bros-Epstein-Glaser theorem.

## Other Lectures and visits

**22 April** – UGent

**8 May** – KULeuven

Regarding the programme of the 2024 Jacques Solvay Chair in Physics, held by Professor Samaya Nissanke, it ended in 2025 with a special workshop on "Gravitational Wave Cosmology" (19 - 21 February 2025). More information on this activity can be found in the Workshops section of this report.

# 2025 International Solvay Chair in Biology

Benjamin Simons
University of Cambridge, United Kingdom

In 2017, following the success of the physics Solvay conference devoted to biophysics, the Institutes were encouraged to develop new initiatives in life sciences. This idea was immediately embraced by the Solvay family. Thanks to their support, along with a special grant from UCB, it has now become a reality. Last year, in 2024, the Institutes held their first Solvay conference on biology. And this year (2025), they proudly launch the Chair programme in biology, mirroring the established chairs in physics and chemistry.

We are truly honoured and grateful that Professor Ben Simons has accepted the invitation to be the 2025 Solvay Professor in Biology. One could not have hoped for a more inspiring start!

The Institutes express also their sincere thanks to Professor Cédric Blanpain, who played a crucial role in inviting Ben, and to Professor Nathan Goldman, who provided invaluable support in organizing the physics component of Ben's visit to Belgium.

The research of Professor Simons integrates experimental, mathematical and computational approaches to study mechanisms of cell fate in epithelial tissues, using mouse genetics and 3D organ cultures. It spans a wide range of topics, from the mechanisms that regulate the development, maintenance, and regeneration of epithelial tissues to how these programmes become dysregulated in the transition to diseased and cancerous states.

His inaugural lecture "Bringing physics to life" was delivered on 1 December in a Solvay room fully packed with biologists and physicists. We reproduce separately excerpts from the introductory speech by Professor Blanpain on page 61. The programme of the first biology chair also involved intense interactions with biophysicists, biologists and physicians from the ULB, the VUB and KULeuven (VIB).

Professor Simons is Director of the Gurdon Institute at the University of Cambridge. After graduating in Cambridge with a PhD in theoretical physics, he undertook postdoctoral training at Massachusetts Institute of Technology. In 1995, he returned to Cambridge as a lecturer in the Cavendish Laboratory, Department of Physics, being appointed to a personal chair in 2002. Currently, he holds the Herschel Smith Chair in Physics and a Royal Society EP Abraham Professorship in the Department of Applied Mathematics and Theoretical Physics. He is a Fellow of the UK's Academy of Medical Sciences and a Fellow of the Royal Society.

# 2025 International Solvay Chair in Biology

## Inaugural lecture

1 December 2025

*"Bringing physics to life"*

From wave-like excitations of atoms in solids to dissipationless transport in superfluids, complex interactions at the microscale often translate into new emergent behaviours at the macroscale. A triumph of 20th Century physics was to understand how such collective phenomena can be encapsulated within the framework of minimal "coarse-grained", hydrodynamic theories. As well as being fundamental in their own right, such phenomenologies provide a common mathematical language to understand cooperative behaviours across a broad range of physical contexts. But does this approach translate to biology? In contrast to physics, the focus in biology is on evolved systems driven far from equilibrium – a hallmark of living systems – where the applicability of such approaches is not guaranteed. Yet, by placing emphasis on the behaviour of statistical ensembles, be they molecules, cells, tissues or communities, concepts from physics can provide a language to address emergent phenomena in biological systems. Here, using case studies from gene silencing memory, stem cell biology and the morphogenesis of branching tissues, I will show how approaches from statistical physics and dynamical systems can provide mechanistic insights into biological processes, from the molecular and cellular to the tissue and organ scale.

Several seminars were organised at ULB on the morning of 1 December in connection with Prof. Simon's work:

Aurore Woller (ULB)
**"Immunity and competition between bacteria in the gut"**

Nikita Frolov (KU Leuven)
**"Beyond Arrhenius: embracing complexity behind temperature scaling of biological processes"**

Paul Van Liedekere (UGent)
**"Agent-based modelling for multicellular systems: overview and some examples"**

## Other Lectures and visits

**10 – 12 December** – VIB (Leuven)

**From the speech by Professor Blanpain introducing Professor Simons before his inaugural lecture:**

"It is a great pleasure to welcome you all to the opening event of the very first Solvay Chair in Biology, hosted by the renowned Solvay Institutes. For more than a century, the Solvay Institutes have been a symbol of scientific excellence in physics and chemistry, a place where some of the most transformative ideas in physics, chemistry, and now biology have emerged.

It is a true honour to contribute to this new chapter in the history of the Solvay Institutes and to celebrate together the first chair in biology awarded to Benjamin Simons.

[...]

Ben is not only one of the world's leading figures in quantitative stem cell and developmental biology - he is also a long-standing collaborator and a dear friend. Over the years, I have had the privilege of having many scientific discussions and making fantastic discoveries with him, and I can say without hesitation that working with Ben has been one of the most stimulating and rewarding collaborations of my career.

Ben's work has profoundly shaped our understanding of tissue dynamics, stem cell behavior, and the early stages of tumorigenesis.

Coming from theoretical physics, he brought to biology an extraordinary conceptual clarity. His development of stochastic stem cell fate models fundamentally changed the way we interpret lineage tracing and clonal dynamics, providing us with a rigorous quantitative language to describe tissue homeostasis, regeneration, and competitive interactions between normal and mutant populations.

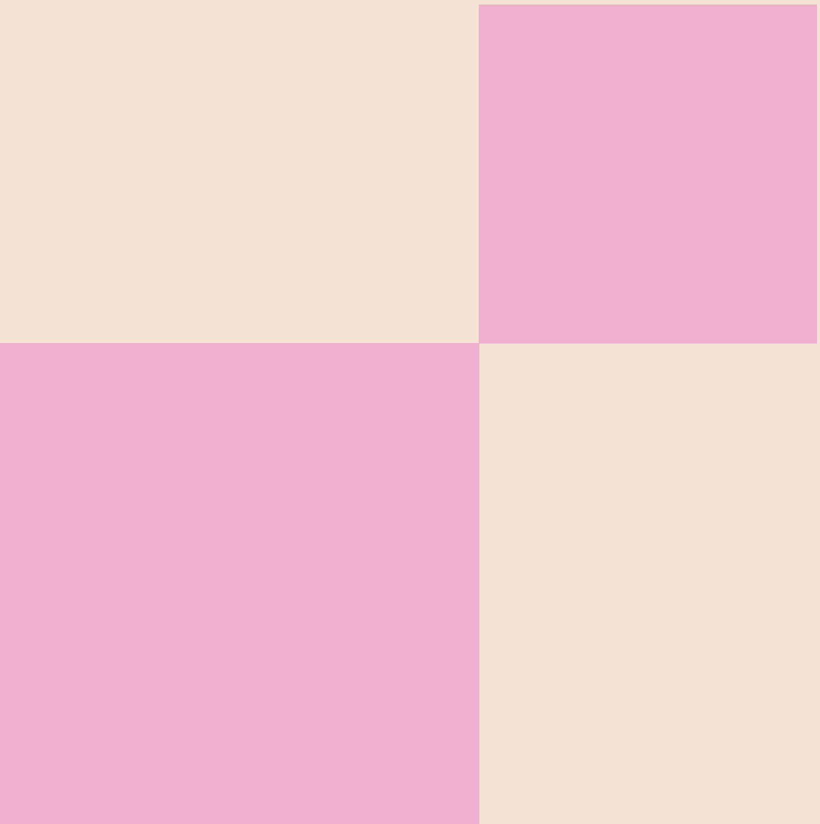
These contributions have not only deepened our understanding of stem cell biology - they have transformed entire fields and influenced how many of us design experiments, interpret data, and think about our research.

But beyond his intellectual brilliance, what sets Ben apart is his humility, his generosity, and his remarkable ability to listen and bring people together. He has built interdisciplinary communities, mentored many exceptional scientists, and played a pivotal role in shaping quantitative biology into a vibrant and collaborative discipline.

As we celebrate the launch of the Solvay Chair in Biology, an initiative built on the ambition to unite disciplines and foster pioneering ideas, it is especially symbolic to welcome a scientist that perfectly embodies these values.

It is therefore with great pleasure, great admiration, and great personal joy that I invite Professor Benjamin Simons to deliver the opening lecture of this historic event."

**Professor Cédric Blanpain**
**ULB**



# New Horizon Lectures

The "New Horizons Solvay Lectures" are given by brilliant young scientists with already high visibility and well-established stature. They deliver one broad lecture at the Solvay Institutes on their current research and the challenges they see for their discipline. A second, complementary lecture is given in another Belgian university. More lectures are encouraged whenever possible.

There are each year "New Horizons Solvay Lectures in Chemistry" and "New Horizons Solvay Lectures in Physics".

This program receives the generous support of the Syensqo company.

## Past New Horizon Lectures

### *Chemistry*

| | |
|---|---|
| 2018 | Alexandre Tkatchenko, University of Luxembourg |
| 2019 | Rafal Klajn, Weizmann Institute, Israel |
| 2020 | Hans Jakob Wörner, ETH Zurich, Switzerland |
| 2021 | Ying Diao, University of Illinois, USA (postponed in 2023) |
| 2022 | Cornelia Meinert, CNRS, Université Côte d'Azur, France |
| 2023 | Danna Freedman, MIT, USA |
| 2024 | Alexis Komor, University of California, San Diego, USA |
| 2025 | Todd Gingrich, Northwestern University, USA |

### *Physics*

| | |
|---|---|
| 2018 | Zohar Komargodski, Weizmann Institute, Israel & Simons Center University of NY, Stony Brook, USA |
| 2019 | Aleksandra Walczak, LPT ENS, Paris, France |
| 2020 | Douglas Stanford, Stanford University, California, USA |
| 2021 | Maria Bergemann, Max Planck Institute, Heidelberg, Germany |
| 2022 | Nir Navon, Yale University, USA (postponed in 2023) |
| 2023 | Alexander Zhiboedov, CERN, Genève, Switzerland |
| 2024 | Netta Engelhardt, MIT, USA |
| 2025 | Kareem J. El-Badry, Caltech, USA |

## Todd Gingrich
Northwestern University, USA

Todd Gingrich is an American theoretical chemist and professor of chemistry at Northwestern University in the United States, who owns a recognized expertise in statistical physics and non-equilibrium thermodynamics, fields that are of great interest for many Belgian chemists. He obtained a B.S. in Chemistry from the California Institute of Technology, a M.Sc. in Theoretical Chemistry from the University of Oxford (as a Rhodes Scholar), and a PhD in Chemistry from the University of California, Berkeley (Hertz Foundation Fellow). His research aims at understanding and modeling chemical systems inspired by living organisms, for example, how molecules use energy to create complex structures or behaviors that are intrinsic to life processes. He elucidated how thermodynamic uncertainty relations constrain non-equilibrium fluctuations. He was awarded a Sloan Research Fellowship, a National Science Foundation career award, a Camille Dreyfus Teacher-Scholar Award, and an Irwin Oppenheim Award from the American Physical Society for work in statistical physics.

## Programme

### Lecture at ULB

1 April 2025

*"Stochastic Molecular Motors and Chemical Reaction Networks Away From Equilibrium"*

Chemical processes exhibit chaotic, high-dimensional dynamics as molecules undergo reactions and diffusion. In the special case of a closed, isolated system, the complex dynamical processes relax into a comparatively simple equilibrium steady-state probability distribution. However, the situation is more complicated when fuel flows into a system and waste flows out. For example, supra-molecular synthetic molecular motors mix reactions and diffusion to convert the fuel energy into directed motion. Away from equilibrium, the theoretical principles and computational methodologies for describing such systems are less well understood. Using open-system molecular dynamics simulations with a minimal model, I will address current reversals, power strokes, and the thermodynamic uncertainty relation. In the second part of my talk, I will discuss tensor-network strategies for studying chemical reaction network dynamics at the level of stochastic kinetics. I will give a flavor of how these methods promise to open up new avenues for studying how reaction networks respond to perturbations.

### Other Lectures and visits

**31 March** - ULuxembourg

**2 April** - KU Leuven

**3 April** - UGent

## Kareem J. El-Badry
Caltech, USA

Kareem El-Badry is an Assistant Professor of Astronomy at the California Institute of Technology. His research focuses on binary stars, black holes, and unusual outcomes of stellar evolution, combining large-scale surveys, targeted observations, and stellar modeling to understand how stars and compact objects form and evolve. He earned his Ph.D. in astrophysics from UC Berkeley in 2021 and was a Junior Fellow at the Harvard/Smithsonian Center for Astrophysics before joining Caltech in 2023. He also holds an adjunct appointment at the Max Planck Institute for Astronomy in Heidelberg, where he has been a frequent visitor since 2016.

## Programme

### Lecture at ULB
2 June 2025

*"The Gaia binary star revolution"*

By precisely measuring the motions of stars on the sky over time, the Gaia mission is conducting a comprehensive census of the Milky Way's binary stars. These data are transformative both for population modeling and for discovery of rare objects. I will describe our emerging view of the populations of black holes, neutron stars, and white dwarfs in au-scale binaries, focusing in particular on their mass, period, and eccentricity distributions. Compared to previous surveys, Gaia is revealing post-interaction binaries in wider orbits, whose properties are difficult to explain with standard binary evolution models. I will discuss how the Gaia catalogs can be leveraged for statistical inference, despite their complex selection function, and how they can discriminate between competing formation models.

### Other Lectures and visits

**3 June** - KU Leuven

**4 June** - ULiège

**5 June** - Royal Observatory

# Workshops organized by the Solvay Institutes

## Gravitational Waves Cosmology
19 – 21 February 2025

The aim of this workshop was to bring together experts working in diverse fields of observational cosmology to address pressing questions that the new observations are currently bringing such as:

- How can we distinguish cosmological sources from the detected Pulsar Timing Array signal?
- What is the nature of the Hubble tension: systematic errors or a sign for new physics?
- How will gravitational waves standard sirens contribute in the near future?
- How to distinguish the primordial gravitational wave background from the astrophysical background?
- Which notable multi-messenger signatures should be searched for?

The week was organised in the context of the 2024 International Solvay Chair in Physics held by Samaya Nissanke.

## Organizing and Scientific Committee

**Giacomo Bruno**
(UCLouvain, Belgium)

**Sébastien Clesse**
(ULB, Brussels, Belgium)

**Geoffrey Compère**
(ULB, Brussels, Belgium)

**Archisman Ghosh**
(Ghent U., Belgium)

**Alberto Mariotti**
(VUB, Brussels, Belgium)

**Samaya Nissanke**
(UvA, The Netherlands)

**Nick Van Remortel**
(Antwerp U., Belgium)

**Alexandre Sevrin**
(VUB, Brussels, Belgium)

## Workshops organized by the Solvay Institutes


### Gravitational Waves Cosmology

### Invited Speakers

James Alvey
(Cambridge U., UK)

Sarah Antier
(Observatoire de la Côte d'Azur, France)

Dillon Brout
(Boston U., USA)

Chiara Caprini
(CERN, Switzerland)

François Foucart
(U. New Hampshire, USA)

Wendy Freedman
(Chicago U., USA)

Archisman Ghosh
(Ghent U., Belgium)

Rachel Gray
(Glasgow U., UK)

Stefan Hild
(Maastricht U., The Netherlands)

Tanja Hinderer
(Utrecht U., The Netherlands)

Justin Janquart
(UCLouvain, Belgium)

Michael Kramer
(Max-Planck, Germany)

Julien Lesgourgues
(RWTH U., Germany)

Chiara Mingarelli
(Yale U., USA)

Andrea Mitridate
(DESY, Germany)

Antonella Palmese
(Carnegie Mellon U., USA)

Adam Riess
(Johns Hopkins U., USA)

Mairi Sakellariadou
(King's College London, UK)

Bernard Schutz
(Max-Planck, Germany)

Licia Verde
(Barcelona U., Spain)

## Programme

### Wednesday 19 February 2025

Opening Session by Samaya Nissanke

Wendy Freedman
*Talk online*

Julien Lesgourgues
*Attempts to explain the Hubble tension with alternative cosmologies*

Bernard Schutz
*The Unexpected Discovery of Standard Sirens*

Rachel Gray
*Cosmology with Dark Sirens and Galaxy Catalogues: a review*

Adam Riess
*Talk online: JWST and the Hubble Tension*

Dillon Brout
*Precision Cosmology with Type Ia Supernovae*

Panel 1: Hubble Tension
Chair: Licia Verde

## Workshops organized by the Solvay Institutes

### Programme

#### Thursday 20 February 2025

Archisman Ghosh
*Gravitational-wave observations: from LIGO-Virgo-KAGRA towards the Einstein Telescope*

Tanja Hinderer
*Gravitational-wave source modeling using analytical relativity*

Stefan Hild
*Einstein Telescope's amazing sensitivity - and will we reach it?*

François Foucart
*Modeling merging neutron stars through numerical simulations*

Sarah Antier
*EM follow up of GW sources*

Antonella Palmese
*Multimessenger measurements and prospects for cosmology with gravitational wave ground based detectors*

Justin Janquart
*Lensed gravitational wave to study the Universe*

Mairi Sakellariadou
*Lightning talks poster session*

## Friday 21 February 2025

Michael Kramer
*Opening a new GW frequency window with Pulsar Timing Arrays*

Chiara Mingarelli
*Astrophysics with Pulsar Timing Arrays: Current Results and Future Directions*

Andrea Mitridate
*The nHz Gravitational Wave Background: evidence and open questions*

Chiara Caprini
*Cosmology with LISA stochastic background and standard sirens*

James Alvey
*Machine Learning for Gravitational Waves: Challenges and Opportunities*

Panel 2: What Are We Missing?
Chairs: Bernard Schutz & Samaya Nissanke

# Workshops organized by the Solvay Institutes

## The interplay of molecules and membranes

28 – 30 April 2025

The aim of this workshop is to bring together speakers from the fields of Chemistry, Physics, and Biology around the question how molecules and ions interact with and cross lipid membranes, addressing different aspects:

- Towards synthetic transport systems for active transport.
- The interaction between synthetic molecules and membranes.
- The partitioning of molecules into membranes.
- Mobility of molecules inside membranes.
- Permeability of molecules across membranes.
- Synthetic transport systems and their applications.
- The implication of active (out of equilibrium) membranes on partitioning/diffusion/transportd be searched for?

## Organizing and Scientific Committee

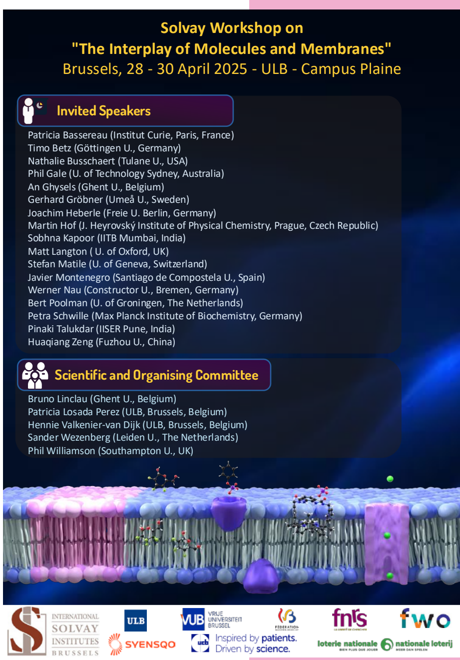
**Bruno Lincla**
(Ghent U., Belgium)

**Patricia Losada Perez**
(ULB, Brussels, Belgium)

**Hennie Valkenier-van Dijk**
(ULB, Brussels, Belgium)

**Sander Wezenberg**
(Leiden U., The Netherlands)

**Phil Williamson**
(Southampton U., UK)



## Workshops organized by the Solvay Institutes

### Invited Speakers

**Patricia Bassereau**
(Institut Curie, Paris, France)

**Timo Betz**
(Göttingen U., Germany)

**Nathalie Busschaert**
(Tulane University, USA)

**Phil Gale**
(U. of Technology Sydney, Australia)

**An Ghysels**
(Ghent U., Belgium)

**Gerhard Gröbner**
(Umeå U., Sweden)

**Joachim Heberle**
(Freie U. Berlin, Germany)

**Martin Hof**
(J. Heyrovský Institute of Physical Chemistry, Prague, Czech Republic)

**Sobhna Kapoor**
(IITB Mumbai, India)

**Matt Langton**
( U. of Oxford, UK)

**Stefan Matile**
(U. of Geneva, Switzerland)

**Javier Montenegro**
(Santiago de Compostela U., Spain)

**Werner Nau**
(Constructor U., Bremen, Germany)

**Bert Poolman**
(U. of Groningen, The Netherlands)

**Petra Schwille**
(Max Planck Institute of Biochemistry, Germany)

**Pinaki Talukdar**
(IISER Pune, India)

**Huaqiang Zeng**
(Fuzhou U., China)

## Programme

## The interplay of molecules and membranes

### Monday 28 April 2025

Welcome and introduction by Hennie Valkenier & Yves Geerts

*Session 1: Interactions and mobility of synthetic molecules in membranes*

Phil Williamson
*Introduction*

Martin Hof
*Physical chemistry of gangliosides nanodomains*

Gerhard Gröbner
*Unravelling the molecular machinery of the Bcl-2 family in apoptosis at mitochondrial membrane level*

Werner Nau
*Interactions of Superchaotropic Cluster Anions with Membranes*

*Session 2: Synthetic transport systems*
Hennie Valkenier
*Introduction*

Matt Langton
*Stimuli-responsive synthetic ion transporters*

Roberto Quesada
*Biologically active anion transporters*

Javier Montenegro
*Dynamic counterion exchange for membrane transport, from amphiphilic to chaotropic carriers*

Phil Gale (Solvay Colloquium)
*Transmembrane anion transport: mechanism, selectivity and control*

Aaron Torres Huerta
*Liposome-Based Nanoreactors: Transmembrane Transport for Controlled Formation of Luminescent Lanthanide Complexes*

Poster Session

## Workshops organized by the Solvay Institutes

### Programme

### The interplay of molecules and membranes

### Tuesday 29 April 2025

*Session 3: Partitioning and permeability of molecules in membranes*

Bruno Linclau
*Introduction*

Shobna Kapoor
*Decoding the role of mycobacterial lipid remodelling and membrane dynamics in antibiotic tolerance*

Gerhard Gröbner
*Unravelling the molecular machinery of the Bcl-2 family in apoptosis at mitochondrial membrane level*

Joseph Lorent
*The synergistic effects of oxidative and acid stress on membrane permeability*

An Ghysels
*Zooming in to the atomic scale: strengths and challenges of simulating partitioning and permeability of membranes*

Bert Poolman
*Synthetic, out-of-equilibrium cell-like systems for directing reaction networks and maintaining homeostasis*

*Session 4: Towards synthetic systems for active transport*

Sander Wezenberg
*Introduction*

Joachim Heberle
*Light-driven halide pumping in protein crystals, detergent micelles, liposomes, and living cells*

Huaqiang Zeng
*Membrane-Active Molecular Machines*

Pinaki Talukdar
*Development of Stimuli-Responsive Artificial Ion Channels*

Julia Villalva
*Visible-light-activation of transmembrane transport by sensitized isomerization*

## Wednesday 30 April 2025

*Session 5: Diffusion/transport across active membranes*

Patricia Losada Perez
*Introduction*

Timo Betz
*Resolving a 100-year-old debate: Is red blood cell membrane flickering active or passive?*

Patricia Bassereau
*Membrane mechanics affects function and clustering of active membrane transporters*

Petra Schwille
*Role of active membranes in the emergence of cell division*

Agur Sevink (Contributed talk)
*Why lipid defects regulate membrane binding*

*Session 6: Interactions with and transport across (bacterial) membranes*

Han Remaut (Contributed talk)
*Nanodomain formation in the bacterial outer membrane*

Nathalie Busschaert
*Lipid head group binding and transmembrane transport: friends or foes?*
Stefan Matile
*New Directions from Synthetic Transport Systems*

## Aromaticity: Celebrating Benzene 200 years

8 - 10 December 2025

### Scientific and Organising Committee

Mercedes Alonso Giner
(VUB, Belgium)

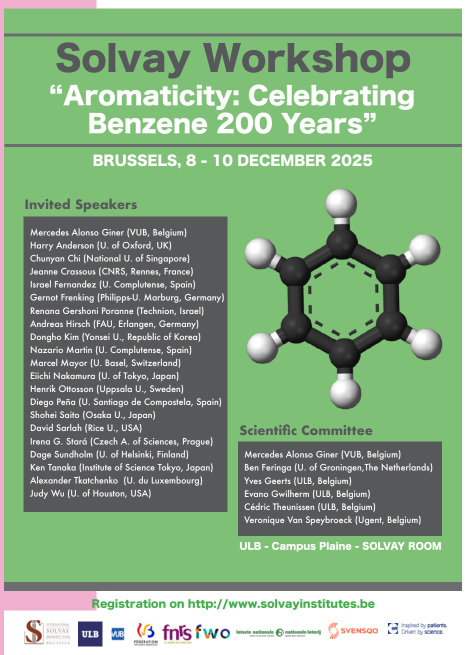
Ben Feringa
(U. of Groningen, The Netherlands)

Yves Geerts
(ULB, Belgium)

Evano Gwilherm
(ULB, Belgium)

Cédric Theunissen
(ULB, Belgium)

Veronique Van Speybroeck
(Ghent U., Belgium)



## Invited Speakers

**Mercedes Alonso Giner**
(VUB, Belgium)

**Harry Anderson**
(U. of Oxford, UK)

**Chunyan Chi**
(National University of Singapore)

**Jeanne Crassous**
(CNRS Institut des Sciences Chimiques de Rennes, France)

**Israel Fernandez**
(U. Complutense, Spain)

**Gernot Frenking**
(Philipps-U. Marburg, Germany)

**Renana Gershoni Poranne**
(Technion, Israel I. of Technology)

**Andreas Hirsch**
(Friedrich Alexander U. Erlangen-Nürnberg, Germany)

**Dongho Kim**
(Yonsei U., Republic of Korea)

**Nazario Martin**
(U. Complutense, Spain)

**Marcel Mayor**
(U. Basel, Switzerland)

**Eiichi Nakamura**
(University of Tokyo, Japan)

**Henrik Ottosson**
(Uppsala U., Sweden)

**Diego Peña**
(U. Santiago de Compostela, Spain)

**Shohei Saito**
(Osaka U., Japan)

**David Sarlah**
(Rice U., USA)

**Irena G. Stará**
(Czech Academy of Sciences, Prague)

**Dage Sundholm**
(U. of Helsinki, Finland)

**Ken Tanaka**
(Institute of Science Tokyo, Japan)

**Alexander Tkatchenko**
(U. du Luxembourg)

**Judy Wu**
(U. of Houston, USA)

# Workshops organized by the Solvay Institutes

## Programme

## Aromaticity: Celebrating Benzene 200 years

### Monday 8 December 2025

Ben Feringa & Yves Geerts
*Introduction and context*

Gernot Frenking
*Aromaticity and Antiaromaticity in the Cyclic 6ϖ and 4ϖ Molecules of Carbon and Silicon E6H6 and E4H4 (E = C, Si)*

Nazario Martin
*The legacy of Benzene: Bilayer Nanographenes in the Age of Precision Carbon Materials*

Irena G. Stará
*First Came Benzene, Then the Twist*

Ken Tanaka
*Catalytic Enantioselective Synthesis of Chiral Nanocarbons*

Renana Gershoni-Poranne
*PAS de Deux: Aromaticity Meets Deep Learning in Polycyclic Aromatic Systems*

Alexander Tkatchenko
*Aromaticity and Dispersion Interactions in Chemistry, Materials Science, and Biology*

Marcel Mayor
*Helical "Geländer"- Structures Propelling Molecular Motors*

Harry Anderson
*How big can they get? What is the size limit of aromaticity?*

## Tuesday 9 December 2025

Chunyan Chi
*π-Structures with Different Topologies: Synthesis, Aromaticity, and Electronic Properties*

Eiichi Nakamura
*Seeing What Faraday Could Only Imagine*

Henrik Ottosson
*On the light-triggered Mr. Hyde character of benzene, H3+ and other aromatic molecules*

Israel Fernandez
*The interplay between aromaticity and reactivity*

Jeanne Crassous
*Molecular engineering of helicenes*

Shohei Saito
*Aromaticity for the Design of Dynamic Molecules and Materials*

Dongho Kim
*Hückel, Möbius, Baird and 3-Dimensional Aromaticity in Various Expanded Porphyrins*

David Sarlah
*Dearomatization of Nonactivated Arenes with Arenophiles*

Judy Wu
*To be announced*

# Workshops organized by the Solvay Institutes

## Programme

### Aromaticity: Celebrating Benzene 200 years

### Wednesday 10 December 2025

Diego Peña
*To be announced*

Andreas Hirsch
*Spherical Aromaticity*

Dage Sundholm
*Aromatic bonding of antiaromatic molecules*

Mercedes Alonso Giner
*Exploring Aromaticity in Expanded Porphyrins: A Multidimensional Approach to Structure–Property Relationships*

Yves Geerts
*Conclusions*

# Workshops sponsored by the International Solvay Institutes

In addition to their regular activities, the Solvay Institutes support a limited number of selected workshops organized by Belgian researchers. These are described below.

## General Scientific Meeting 2025 of the Belgian Physical Society

28 May 2025, UCL, Louvain-la-Neuve

The General Scientific Meeting of the BPS (Belgian Physical Society) was held at UCL in Louvain-la-Neuve on May 28, 2025. The supervisor of the local organizing committee was Prof. Xavier Urbain, UCL together with a team of his colleagues.

The General Scientific Meeting of the Belgian Physical Society covers all main fields of physics research in Belgium. The research can be carried out at any Belgian university or research institute. Research concerning physics education (at secondary school and high school/university level) and physics research in the industry is also included.

**Parallel sessions and poster session:**

- Astrophysics, Geophysics, and Plasma Physics.
- Biophysics, Medical, Mathematical and Statistical physics.
- Condensed Matter and Nanostructure physics.
- Fundamental interactions, Particle and Nuclear Physics.
- Mathematical and statistical physics, theoretical astronomy.
- Physics and Education.
- Atoms, Molecules, Optics and Photonics.

### Programme

Plenary session

Welcome address by the President of the BPS, Jozef Ongena

**Antoine Browaeys**
(Laboratoire Charles Fabry, Institut d'Optique and U.Paris-Saclay, France)
*Assembling quantum matter one atom at a time*

**Tim Palmer**
(Oxford University, Royal Society Research Professor in Climate Physics)
*Chaos, noise and uncertainty: enemies or allies for predicting weather and climate?*

Young speaker contest

Walking Lunch and Posters

Parallel sessions

## The Holographic Universe

2 to 6 June 2025, STUK Aula City Center Leuven

Organised by Nikolay Bobev (KU Leuven), Thomas Mertens (U Gent), Christoph Uhlemann (VUB)

Holographic dualities have played a key role in recent developments across many areas in theoretical physics, ranging from black holes and quantum chaos to fundamental aspects in quantum field theory and string theory. This 5-day workshop will bring together a diverse group of international experts leading recent advances in the field of holography, broadly speaking. Focus topics include 2d gravitational models and black holes, conformal field theory constraints on the holographic landscape, geometric aspects of top-down AdS/CFT, and features of AdS black holes in connection with holography. The intended program will feature one broad review talk per day and a selection of more specialized shorter talks. In order to further facilitate an exchange of ideas and to foster new collaborations, the program will also include discussion sessions. A poster session will serve as platform for junior researchers to contribute.

### Speakers

**João Penedones**
(EPFL Lausanne)

**Gustavo Joaquin Turiaci**
(University of Washington)

**Eric Perlmutter**
(IPhT Saclay)

**James Sparks**
(Oxford University)

**Jorge Santos**
(Cambridge University)

### Research talks

Andreas Blommaert, Elli Pomoni, Beatrix Mühlmann, Suzanne Bintanja, Davide Cassani, Stefano Giusto, Fabio Apruzzi, Severin Lüst, Julius Julius, Pietro Ferrero, Diego Hofman, David Kolchmeyer, Olga Papadoulaki, Pranjal Nayak.

## Workshops sponsored by the International Solvay Institutes

### BQPi Workshop, held in honor of Ignacio Cirac and Peter Zoller

3 October, 2025, University Foundation, Brussels

In order to celebrate Professors Ignacio Cirac and Peter Zoller, who received the 2025 Annual Prize of the "Académie Royale de Belgique", a special workshop was held in their honor on October 3 at the University Foundation.

Both Professors Cirac and Zoller have close ties with the Solvay Institutes. Professor Cirac will hold the 2026 Jacques Solvay Chair in Physics. Professor Zoller held the 2015 Jacques Solvay Chair in Physics and is a Member of the International Scientific Committee for Physics of the Institutes. Both participated in many Solvay conferences.

#### Programme

**Ignacio Cirac** (MPQ)
*Quantum simulation in the presence of errors*

**Peter Zoller** (IQOQI)
*Quantum simulation with atomic platforms*

**Nick Bultinck** (UGent)
*Extracting average properties of disordered spin chains with translationally invariant tensor networks*

**François Damanet** (ULiege)
*Controlling matter phases beyond Markov*

**Alessio Lerose** (KULeuven)
*Interface dynamics in synthetic quantum magnets: from theory to quantum simulation*

**Laurens Vanderstraeten** (ULB)
*Simulating the Bose-Hubbard model with tensor networks*

**Michiel Wouters** (UAntwerp)
*Kardar Parisi Zhang scaling in polariton and photon condensators*

## Beyond Boundaries: Sciences, Art and Society: "Fractures et Résistances"

18 October 2025, Collegium, Belgium Royal Academy

### Programme

Introduction by Thomas Verdebout, Directeur du Collegium

**Kintsugi - Dance & Drums**
Tagawa (danse)
Isabella Soupart (choreography)
Antoine Pierre (drums)

**Ramona Coman**
*La contestation de la démocratie libérale en Europe*

**Olivier Klein**
*Polarisation et Complotisme sous le prisme de la psychologie sociale*

**Géraldine Boseret**
*Pandémie : l'ennemi microscopique reconstructeur d'un monde*

**Conclusion**

Cocktail

Concert - De Beren Gieren

## Structure and Function of Biological Macromolecules, Bioinformatics and Modelling (SFMBBM) PhD day 2025

14 November 2025, ULB

The SFMBBM (Structure and Function of Biological Macromolecules, Bioinformatics, and Modelling) FNRS Graduate School held its annual One-Day Symposium, which is specially dedicated to PhD students, at the Université Libre de Bruxelles (ULB).

This was an inter-university initiative.

The graduate school SFMBBM was created in order to:

- Promote the doctoral training in closely interconnected scientific fields such as biochemistry of macromolecules, structural biology, proteomics, bioinformatics and modelling.
- Promote contacts between PhD students during their doctoral training.
- Provide scientific background and knowledge as well as human resources to help the PhD student at the beginning of his scientific career.
- Allow access to expensive or state of the art techniques distributed across the country: NMR, X-ray diffraction, high-end spectroscopy (e.g., FTIR), informatic resources and algorithms, proteomic techniques (mass spectrometry, separation techniques, automated peptide synthesis and analysis, sequencing techniques, etc.)
- Enable national and international interactions during scientific meetings (e.g., seminars, meetings, summer schools, training courses, etc.)
- Prepare PhD students to professional life (academic or industrial) by providing interpersonal skills and by building their self-confidence through oral presentations and international exchanges, to develop their capacity to communicate in English through the redaction of scientific publications, international projects and personal reports.

## Professor Robbert Dijkgraaf

University of Amsterdam, The Netherlands

17 February 2025

*"The Future of European Science and Innovation"*

A series of recent studies, in particular the Draghi report, have brought in clear focus the challenges for Europe to address societal issues while being a competitive economy at a global scale. Research and innovation should be at the center of such a future-directed strategy. What are the options to grow Europe's power as a modern knowledge-based society, both at the national and European level? How should Europe orient itself in times of geopolitical stress and worldwide inward-looking tendencies?

Professor Robbert Dijkgraaf chairs the International Advisory Committee of the International Solvay Institutes. He was Director of the Institute for Advanced Study at Princeton (2012-2022), the president of the Dutch Royal Netherlands Academy of Arts and Sciences (2008-2012), and more recently, Minister of Education, Culture and Science in the Netherlands (2022-2024). Among his many distinctions, he holds an honorary degree from the VUB.

Professor Jean-François Joanny
Collège de Fance, Paris

18 March 2025

*"Self-organized patterns of microtubules and molecular motors"*
(JF Joanny, S. Pattanayak, A. Sciortino, L. Blanchoin and M. Théry)

The internal organization of cells is largely determined by the architecture and orientation of the microtubule network. Microtubules serve as polar tracks for the selective transport of specific molecular motors toward either their plus or minus ends.

We present experiments on reconstituted systems and theory to study the interaction of microtubules with both plus-and minus-end directed motors bound to a fluid membrane. Depending on motor concentrations, the system leads either to the constant transport of microtubules or to their alignment, stacking, and immobilization in regular bands that separate motors into domains of opposite polarities.

In bands, microtubules all share the same polarity and segregate the two opposing motors accordingly. These regular patterns result from the balance of forces produced by the two motors as they walk in opposite directions along microtubules.

The patterns result from active microphase separation where the microtubules can be considered as active surfactants pumping the motors on each side depending on their polarity. We present a model for the steady state patterns in one and two dimensions and an active Cahn Hilliard theory, wich describes the kinetics of the phase separation.

Professor Lutz Ackermann
Georg-August-Universität Göttingen, Germany

20 March 2025

*"Current Aspects of Electrocatalysis with Potential"*

Oxidative C–H activation has emerged as an increasingly powerful tool in molecular syntheses.[1] Despite major progress towards atom and step economy, these transformations largely rely on precious metal catalysts and stoichiometric amounts of toxic metal oxidants, compromising the overall sustainability of the C–H activation strategy.

In contrast, employing electrooxidation in lieu of reactive chemical oxidants prevents undesired waste formation through oxidant economy and offers efficient use of renewable energies from sustainable sources for chemical bond formation.[2] Inexpensive Earth-abundant 3d metal[3] cobaltaelectrocatalysis set the stage for molecular syntheses at a unique level of resource economy. Our studies towards metallaelectrocatalytic C–H and C–C activation, data science[4] and enantioselective[5] electrocatalysis will be discussed, with a topical focus on sustainable base metals.

[1] a) L. Ackermann, Acc. Chem. Res. 2014, 47, 281–295; b) C. S. Yeung, V. M. Dong, Chem. Rev. 2011, 111, 1215–1292.
[2] a) P. Gandeepan, L.H. Finger, T.H. Meyer, L. Ackermann, Chem. Soc. Rev. 2020, 49, 4254–4272; b) L. Ackermann, Acc. Chem. Res. 2020, 53, 84–104. c) C. Ma, P. Fang, T.-S. Mei, ACS Catal. 2018, 7179–7189.
[3] P. Gandeepan, T. Müller, D. Zell, G. Cera, S. Warratz, L. Ackermann, Chem. Rev. 2019, 111, 2192–2452.
[4] Z. Lin, U. Dhawa, X. Hou, M. Surke, B. Yuan, S.-W. Li, Y.-C. Liou, M.J. Johansson, L.-C. Xu, C.-H. Chao, X. Hong, L. Ackermann, Nat. Commun. 2023, 14, 4224.
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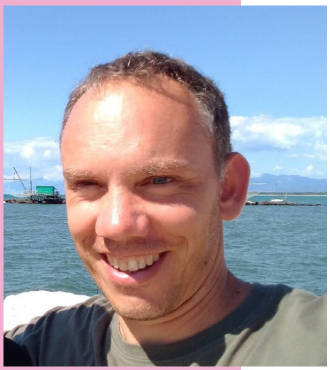


Professor Iacopo Carusotto
INO-CNR BEC Center, Trento, Italy

15 April 2025

*"Quantum superfluids as analog models of gravity: a fruitful synergy of gravity and quantum optics"*

In this talk, I will present the state of the art and the new perspectives in the theoretical and experimental work on the quantum simulation of gravitational problems using condensed matter and optical systems, the so-called analog models of gravity.

I will start with a general introduction to the general concept of analog model and a review of milestone theoretical and experimental works on Hawking emission of phonons from acoustic horizons in trans-sonic flows of ultracold atoms.

I will then present the on-going theoretical and experimental studies of false vacuum decay processes at the Pitaevskii BEC Center: I will present experimental evidence of the decay of an extended metastable state via the nucleation of spatially localized bubbles in a two-component atomic superfluid and I will highlight its connection to open questions in quantum field theory and cosmology.

# Colloquia

## Professor Philip A. Gale
University of Technology Sydney, Australia

28 April 2025

### *"Transmembrane anion transport: mechanism selectivity and control"*

Facilitating anion transport across lipid bilayers by small molecules is an area of intense current interest due to the potential application of these compounds in the treatment of diseases such as cancer and cystic fibrosis. Several different approaches have been taken by groups worldwide including the development of synthetic channels [1] and small molecule discrete transporters.[2]

This colloquium will focus on work conduced in our research group following the development of transporters and assays to understand transport mechanisms,[3] the development of selective transporters and the role of fatty acids in selectivity,[4] how transport can be controlled using external stimuli [5] and how anion transporters affect the function of cells.[6]

This work was supported by the Engineering and Physical Sciences Research Council (UK) Australian Research Council, the University of Southampton, the University of Sydney and the University of Technology Sydney.

1. V. Gorteau, G. Bollot, J. Mareda, A. Perez-Velasco and S. Matile, J. Am. Chem. Soc., 2006, 128, 14788-14789. 2. A.J. Ayling, M. N. Pérez-Payán and A.P. Davis, J. Am. Chem. Soc. 2001, 123, 12716-12727. 3. X. Wu, E.N.W. Howe and P.A. Gale, Acc. Chem. Res. 2018, 51, 1870-1879; X. Wu and P.A. Gale, Chem. Commun. 2021, 57, 3979-3982. 4. X. Wu, L.W. Judd, E.N.W. Howe, A.M. Withecombe, V. Soto-Cerrato, H. Li, N. Busschaert, H. Valkenier, R. Perez-Tomas, D.N. Sheppard, Y.-B. Jiang, A.P. Davis and P.A. Gale, Chem, 2016, 1, 127-146; E.N.W. Howe and P.A. Gale, J. Am. Chem. Soc. 2019, 141, 10654-10660. 5.M. Fares, X. Wu, D. Ramesh, W. Lewis, P.A. Keller, E.N.W. Howe, R. Pérez-Tomás and P.A. Gale, Angew. Chem. Int. Ed., 2020, 59, 17614-17621; S.J. Wezenberg, L.-J. Chen, J.E. Bos, B.L. Feringa, E.N.W. Howe, X. Wu, M.A. Siegler and P.A. Gale, J. Am. Chem. Soc. 2022, 144, 331-338. 6. N. Busschaert, S.-H. Park, K.-H. Baek, Y.P. Choi, J. Park, E.N.W. Howe, J.R. Hiscock, L.E. Karagiannidis, I. Marques, V. Félix, W. Namkung, J.L. Sessler, P.A. Gale and I. Shin, Nature Chem., 2017, 9, 667-675; S. Cheung, D. Wu, H.C. Daly, N. Busschaert, M. Morgunova, J.C. Simpson, D. Scholz, P.A. Gale and D.F. O'Shea, Chem, 2018, 4, 879-895; S.-H. Park, S.-H. Park, E.N.W. Howe, J.Y. Hyun, L.-J. Chen, I. Huang, G. Vargas-Zuñiga, N. Busschaert, P.A. Gale, J.L. Sessler, I. Shin, Chem, 2019, 5, 2079-2098; W. G. Ryder, M.E. Graziotto, A. Levina, B.A. Hawkins, D.E. Hibbs, E.J. New and P.A. Gale, Chem, 2025, 11, 102247.

Professor Véronique Van Speybroeck
Ghent University Belgium

12 May 2025

***"New avenues in modeling nanoporous materials and their applications at crossroads of quantum mechanics, statistical physics and machine learning"***

Nanoporous materials are omnipresent in the fields of catalysis, sorption, sensing and crucial for future technologies. Modelling is pivotal to understand the function of nanoporous materials. Ideally it would be possible to design the right material with atomic scale precision for the desired macroscopic function. Modeling realistic functional nanomaterials poses significant challenges. Firstly, nanostructured materials used in applications are far from perfect, they possess a broad range of heterogeneities in space and time extending over several orders of magnitude. Spatial heterogeneities from the subnanometer to the micrometer scale in crystal particles with a finite size and specific morphology, impact the material's dynamics. Secondly, the material's functional behaviour is largely determined by the operating conditions. Currently, there exists a huge length-time scale gap between attainable theoretical length-time scales and experimentally relevant scales.

A first important ingredient for modelling nanostructured materials is an accurate representation of the interatomic interactions. Ideally very accurate quantum mechanical methods are used for this purpose. Despite the availability of powerful high-performance computers and the development of advanced methods and algorithms, solving the quantum mechanical many-body problem directly for system sizes comparable to experimental systems remains infeasible.

A second crucial aspect of the modeling exercise is the sampling problem of the multidimensional potential energy surface. Identifying interesting regions in phase space is challenging due to the many degrees of freedom involved. To address this, advanced enhanced sampling methods have been developed, however often these rely on chemical intuition.

Recently new avenues have emerged in modelling nanostructured materials thanks to methodologies integrating concepts from machine learning, quantum mechanics and statistical physics. One notable development is the ability to determine energies and forces using numerical Machine Learning Potentials (MLPs) derived from underlying quantum mechanical data.

To fully integrate MLPs into the catalysis or materials design workflow, it is essential to efficiently generate training data that accurately represent the highly dimensional Free Energy Surface while maintaining chemical accuracy. Addressing this challenge requires methodological advancements that enable the coupling of MLPs with kinetic and sampling models to describe complex dynamical phenomena across a broad range of length and time scales. Within this talk, I will show some of our recent endeavours in this direction. As will become clear realistic nanomaterials requires a multidisciplinary vision between physics, chemistry, material science, engineering and machine learning. The methods will be illustrated on timely applications in the fields of heterogeneous catalysis, adsorption and sensing using nanoporous materials.

Professor Michael Douglas
Harvard University, USA

16 June 2025

*"AI in math and theoretical physics: status and prospects"*

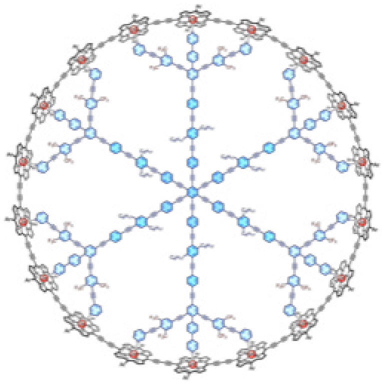
AI progress is accelerating, and now the leaders expect "artificial general intelligence" (AGI) in 2 to 3 years. While difficult to believe, we must prepare for the possibility. We can take some lessons from previous episodes in which computers surpassed humans, for example in chess. We survey current trends in AI for math and discuss conceptual studies of mathematical copilots and systems for autonomous mathematical discovery. These seem likely to me to become truly useful in the next few years.

Professor Harry L. Anderson
Oxford University, UK

8 December 2025

*"How big can they get? What is the size limit of aromaticity?"*

(Anti)aromaticity arises in molecules with electrons that are delocalized around a circular pathway. Its clearest manifestation is a ring current that is diatropic (aromatic) when the circuit has 4n+2 electrons or paratropic when it has 4n electrons. These ring currents are easily detected by NMR spectroscopy. Most aromatic systems are small rings with up to about 22 ϖ-electrons. In this lecture, experimental evidence will be presented for global ring currents in macrocycles such as the 18-porphyrin nanoring shown below (diameter 8 nm; 242 ϖ-electron circuit in 10+ oxidation state), in which they provide a signature for electronic delocalization.[1-4]



References: [1] M. Rickhaus, et al. Nat. Chem. 2020, 12, 236. [2] M. Jirásek, et al. Acc. Chem. Res. 2021, 54, 3241. [3] J. M. Holmes, et al. J. Am. Chem. Soc. 2025, 147, 32840. [4] A. Rodríguez-Rubio, et al. Science 2025, 390, 290.

## Doctoral Schools

### XXI Modave

#### 1 - 5 September 2025, Modave

The Modave Summer School in Mathematical Physics is a yearly summer school organised by and aimed at Ph.D. students. The school provides blackboard lectures given by young researchers, mostly postdocs, coming from institutions all over Europe. The lectures cover core subjects that contribute to the backbone knowledge of the participants working in the field of theoretical and mathematical physics, with a special focus on topics in General Relativity, Quantum Field Theory and String Theory. It also aims to encourage interactions between Ph.D. students from belgian and foreign institutions. During this 21st edition, about half of the participants came from belgian universities, and the other half from further in Europe.

### Organising Committee

**Guillermo Mera Álvarez**
(KULeuven)

**Thomas Tappeiner**
(UGent)

**Augustin Basilavecchia**
(ULB)

**Sylvain Thomée**
(UMons)

**Seppe Geukens**
(VUB)

### Program

#### Jackson Fliss

***Energy conditions in classical and quantum field theory, and semi-classical gravity***

Energy conditions play an important role in gravitational physics: through the Einstein equation, constraints on the local distribution of energy translate to constraints on physically realizable spacetimes. I will review well known classical energy conditions and their implications

## XXI Modave

for gravitational solutions, such as the celebrated Hawking and Penrose singularity theorems. This topic becomes both richer and more subtle when considering quantum fields coupled to gravity as even the simplest quantum theories violate local energy conditions. I will discuss directions for suitably constraining energy densities in quantum field theories, including averaging over regions of spacetime and bounds relating energy and quantum information. I will explore implications of these bounds for quantum field theory coupled to gravity as an effective theory.

### Javier Subils

***Holographic confinement and its probes***

Confinement and the existence of a mass gap are among the most challenging phenomena to understand in quantum field theory. One of the strengths of holography is its ability to offer an intuitive (geometric) realization of confinement. In these lectures, after introducing the AdS/CFT correspondence, I will explain how confinement can be "understood" via the gravitational dual of a gauge theory. In particular, I will review the physics of some of the most iconic confining holographic setups, such as the Witten soliton or the Klebanov–Strassler solution.

### Matilda Delgado

***From Symmetries to Branes: Dynamical Implications of the Cobordism Conjecture***

This lecture series will review a core principle of the Swampland program: that consistent theories of quantum gravity forbid exact global symmetries. We begin with a pedagogical overview of this conjecture, its motivation from black hole physics, and its modern generalizations to higher-form and other generalized global symmetries. The second half of the course will focus on the Cobordism Conjecture, which provides a sharp topological perspective on this principle. We will explain how cobordism classes can be associated with generalized symmetries in the low-energy theory, and how quantum gravity is expected to eliminate these symmetries. This leads to the prediction of new extended objects, whose properties and dynamics we will examine in detail.

## Simon Ekhammar

### *Introduction to Quantum Spectral Curve and the Spectrum of N=4 Super Yang-Mills*

Finding the full spectrum of a four-dimensional conformal field theory is a highly challenging problem. Excitingly, there has been tremendous progress in achieving this goal in planar four-dimensional maximally supersymmetric Yang-Mills theory (N=4 SYM), a theory which, through the AdS/CFT correspondence, is also dual to strings propagating on AdS5 × S5. The key to this progress lies in the surprising fact that planar N=4 SYM appears to be integrable, allowing the use of powerful tools not typically at our disposal. In these lectures, I will first describe how to use integrability to find the spectrum of rational spin chains, one of the simplest integrable models. Thereafter, building on this foundation, we will attack N=4 SYM, exploring the most modern formulation of integrability in N=4 SYM: the Quantum Spectral Curve.

## XXI Modave

### Participants

Adrien Arbalestrier
Fabrizio Aramini
Augustin Basilavecchia
Maël Chantreau
Matilda Delgado
Vladan Djukić
Corinne Englert
Simon Ekhammar
Osman Erkan Kaluç
Jackson Fliss
Seppe Geukens
Jamal Hammoud
Blanca Hergueta
Axel Hrelja
Guillermo Mera Álvarez
Louan Mol
Adrien Molines
Pietro Moroni
Noémie Parrini
Sébastien Robert
Thomas Smoes
Javier Subils
Alex Swash
Thomas Tappeiner
Sylvain Thomée
Eduardo Velasco
Sara Zeko

## Doctoral School on "Quantum Field Theory, Strings and Gravity"

The aim of the Amsterdam-Brussels-Geneva-Paris Doctoral School on "Quantum Field Theory, Strings and Gravity" is to provide first-year PhD students with advanced courses in theoretical physics that help bridge the gap between Master-level courses and the most recent advances in the field. Responsible for the organization as well as for teaching the courses are the ULB, the VUB, the University of Amsterdam, various institutions in Paris led by Ecole Normale Supérieure, and various institutions in Switzerland led by the Swiss network "SwissMap" (ETH, U. Bern, U. Geneva, CERN).

The program typically starts at the end of September/beginning of October and consists of three times three weeks of lectures in three cities among Amsterdam, Brussels, Geneva (CERN) and Paris (depending on the year), with a one-week break between the segments. This way, the students are exposed to several institutes, each with their own research and teaching culture, and to professors from the various institutes. Last but not least, they get to meet fellow students from neighbouring institutes and countries, who will be their peers and colleagues throughout (and possibly beyond) their PhD studies.

## Participating Institutions

Institute for theoretical physics - University of Amsterdam

Laboratoire de physique théorique - Ecole Normale Supérieure (Paris)

Physique théorique et mathématique - ULB

Theoretical particle physics - VUB

SwissMap (ETH, U. Bern, U. Geneva, CERN)

## Organizing Committee Brussels

**Riccardo Argurio**
(ULB)

**Ben Craps**
(VUB)

**Frank Ferrari**
(ULB)

## Doctoral School on "Quantum Field Theory, Strings and Gravity"

### Program

#### Brussels | 6 - 24 October 2025

**Adel Bilal**
Advanced Quantum Field Theory

**Marco Billó**
Introduction to String Theory

**Roberto Emparan**
Advanced General Relativity and Black Holes

**Alberto Lerda**
Introduction to String Theory

#### Paris | 3 - 21 November 2025

**Mariana Grana**
Superstrings and D-branes

**Elias Kiritsis**
Dualities in string theory

**Silvia Penati**
Introduction to supersymmetry

**Antoine van Proeyen**
Supergravity

#### Amsterdam | 1 - 19 December 2025

**Alex Belin**
Black holes and quantum chaos

**Lorenz Eberhardt**
2d CFT and 2d gravity

**Kyriakos Papadodimas**
AdS/CFT

**Antony Speranza**
Algebraic approach to quantum gravity

**Balt van Rees**
Introduction to bootstrap

## Participants

Aguayo Monserrat

Arif Amine

Biancotto Mattia

Cardinale Leonardo

Chabirand Victor

Chen Chutian

Cordoba Lopez Rafael

Creed Brian

D'Exelle Cédric

De Vito Alice

Di Salvo Enrico

Dujava Jonáš

Fragoso Duarte

Ghiringhelli Paul

Guillen Philippe

Guo Lihan

Herček Filip

Landry Robin

Ligorio Michele

Marion Nils

Möckli Yannis

Mtchedlidze Mariami

Osorio Navarro Loreto Soledad

Pierratos Michailangelos

Ramirez de Arellano Cielo

Spinielli Giovanni

Tran Quang Loc

Van de Plas Inne

Villey Antoine

Vinck Luka

# 05

# RESEARCH & RESEARCHERS

# Research and Researchers

These sections successively describe:

- The research carried out in the groups of Professors Marc Henneaux, Executive Director and Director for Physics, and Alexandre Sevrin, Deputy Director for Physics and Scientific Secretary of the International Scientific Committee for Physics ("research on gravitation, strings and cosmology").
- The research carried out in the group of Professor Yves Geerts, Director for Chemistry.
- The research carried out in the group of Professor Nathan Goldman, group leader at the Institutes.
- The research highlights of other scientists connected with the Institutes.

# Gravitation, string theory and cosmology group

## Researchers ULB

### Faculty Members

Riccardo Argurio
(ULB)

Glenn Barnich
(ULB)

Vladimir Belinski
(ICRAN, Italy)

Andrès Collinucci
(ULB)

Geoffrey Compère
(ULB)

Nathalie Deruelle
(ULB & CNRS)

Stéphane Detournay
(ULB)

François Englert
(ULB, Honorary Member of the Institutes)

Frank Ferrari
(ULB)

Marc Henneaux
(ULB)

Axel Kleinschmidt
(Max-Planck-Institute, Potsdam, Germany)

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(ULB)

### Postdoctoral Researchers

Soumyadeep Chaudhuri
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Kévin Nguyen
(ULB)

Gabriel Andres Piovano
(ULB)

Jakob Salzer
(ULB)

Colin Sterckx
(ULB)

Stathis Vitouladitis
(ULB)

## Gravitation, string theory and cosmology group

### Graduate Students

Adrien Arbalestrier
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(ULB)

Sébastien Robert
(ULB)

Thomas Smoes
(ULB)

Wen-di Tan
(ULB)

Romain Vandepopeliere
(ULB)

## Researchers VUB

### Faculty Members

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Alexandre Sevrin
(VUB)

Christoph Uhlemann
(VUB)

### Part-time Researchers

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Oleg Evnin

Laura Lopez Honorez

### Postdoctoral Researchers

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(VUB)

Pratik Nandy
(VUB)

Jacopo Nava
(VUB)

Andrew Rolph
(VUB)

Paolo Vallarino
(VUB)

### Graduate Students

Enrico Di Salvo
(VUB)

Hannah Duval
(VUB)

Seppe Geukens
(VUB)

Maxime Grandjean
(VUB)

Dongming He
(VUB)

Niranjan Kamath
(VUB)

Maria Knysh
(VUB)

Xander Nagels
(VUB)

Gabriele Pascuzzi
(VUB)

Maxim Pavlov
(VUB)

Aäron Rase
(VUB)

Elise Van den Bossche
(VUB)

# Gravitation, string theory and cosmology group

## Research Summary

### Research On Gravitation, Strings and Cosmology

Of all the fundamental forces (electromagnetism, gravitation, weak and strong nuclear forces), gravity remains the most mysterious. In spite of its remarkable successes, Einstein's general theory of relativity, which has led to an unprecedented geometrization of physics, is an unfinished revolution. A major challenge of modern physics is to reconcile quantum mechanics and Einstein's gravity. This will undoubtedly need new developments that will go beyond Einstein's revolution. Fully unravelling the mysteries of the gravitational force is a long-term research goal.

The group has a long-standing interest and a demonstrated expertise in quantum gravity, quantum field theory, string theory and M-theory, black holes, cosmology, the cosmological constant problem ("dark energy") and the novel mathematical structures underlying these questions. These challenging areas raise many of the most profound issues in theoretical physics. A central thread in the study of gravity and the fundamental interactions is the concept of symmetry (global and local). Two lines of investigation have been in particular vigorously pursued recently: developing flat space holography and understanding the role of quantum information and complexity in quantum gravity.

The direct detection of gravitational waves has opened in recent years a spectacular new window on the universe. The group has also invested major efforts towards developing new analytical and numerical tools for analyzing gravitational radiation and is involved as well in the development of new detectors.

### Research carried out in 2025

We have continued our research along the general directions outlined above. This has led to 107 published papers and preprints submitted for publication. These are listed on pages 146-152. Specific achievements by some researchers from the group are described in the subsequent pages.

The research of the director and of his group has benefited, as in the previous years, of gifts from the Solvay family and the Syensqo Group. This generous support was precious to cover international collaborations, the organization of workshops as well as doctoral and postdoctoral grants to researchers. It is most gratefully acknowledged.

## 2025 Marina Solvay Fellowships

Thanks to a special gift of Mrs. Marina Solvay, the "Marina Solvay Fellowship" was created in 2012. The fellowship enables a brilliant young researcher to pursue her or his career as a postdoctoral fellow in the group of "physique théorique et mathématique" of the ULB.

### Previous Marina Solvay fellowship:

2012 - 2014
**Waldemar Schulgin**

2015
**David Tempo**

2016
**Jelle Hartong**

2017
**Adolfo Guarino**

2018
**Charlotte Sleight**

2019
**Sucheta Majumdar**

2020
**Oscar Fuentealba**

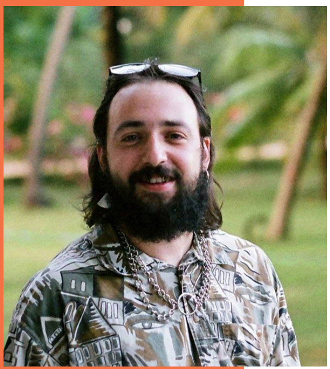
2021
**Luca Ciambelli**

2022
**Jakob Salzer**

2023 and 2024
**Oscar Fuentealba**

2025
**Stathis Vitouladitis**

# Gravitation, string theory and cosmology group



## Stathis Vitouladitis

**Stathis Vitouladitis** earned a PhD in Physics from the University of Amsterdam in 2024, before joining the group of the Director at ULB. Stathis's research explores the structure of quantum field theory and quantum gravity, often drawing inspiration from condensed matter and quantum information. Ongoing themes include generalised symmetries, entanglement, and topological phases, as well as applications to quantum aspects of cosmological spacetimes. Recent contributions address entanglement order parameters, quantum anomalies, extended operators and excitations, and infinite-dimensional algebras in field theory.

### New uses of symmetry in quantum field theory

Symmetry lies at the heart of modern physics. It underpins our understanding of conserved quantities, such as energy, momentum, or particle number, and it results in "selection rules" which govern the dynamics of physical systems. Symmetries are not just aesthetically pleasing, but a useful computational tool.

Recently, our understanding of symmetry has taken on a topological flavour. Conserved quantities no longer concern just particles, but also extended objects, like strings and membranes. This kind of generalisation, **higher-form symmetry**[1], abounds in well-known physical systems, like plain old electromagnetism, and even the Standard Model of particle physics. Then come **non-invertible symmetries**[2] a more exotic, though surprisingly common, generalisation. These are symmetries which cannot always be undone, and are thus beyond the standard group theoretic description. They appear in many critical systems, such as the Ising model, and are increasingly important for deciding what features of a theory are really universal.

My research looks at how these generalised symmetries shape quantum systems, especially through the lens of **quantum field theory** (QFT). QFT is a reliable framework which describes particles, and fields, and surprisingly many things that are not particles or fields.

It is structured enough to be doable, but complicated enough to be useful. In the background is a bigger goal: to (cautiously) take these lessons into murkier waters, in particular, **quantum gravity**.

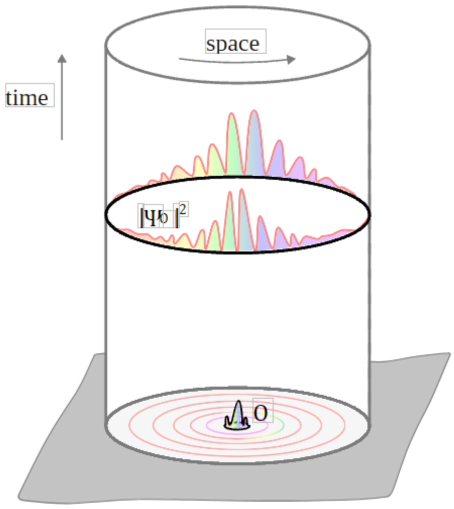



Figure 1: A sketch of the state-operator correspondence. A local operator, O, is inserted on the plane. It evolves radially until it reaches a spatial slice of radius r, where it defines a state, ΨO. Conversely, every state of fixed energy can be written this way.

This year, one focus of mine was understanding how symmetry constrains the space of possible quantum states, wavefunctions smeared across space. These may be uniformly spread out, sharply localised, or vary in more intricate ways. For a special class of theories, **conformal field theories**, that are invariant under rescalings, there is a beautiful result: every state can be prepared by inserting an operator at a point. This is the so-called **state-operator correspondence**, and it rests on the idea that in a scale-invariant theory, all the information about a state can, in a sense, be compressed into a single point.

I asked whether this sleight of hand still works in theories that are not scale-invariant, but still have a rich enough symmetry structure. In particular, I looked at systems that have a dual conservation law: one conserving particle and one conserving higher-dimensional objects known as **vortices**. These turn up precisely in a phase of matter known as a **superfluid**. In my work[3], I discovered that the state-operator correspondence continues to apply: every wavefunction in such systems is still locally preparable. This alludes to a deeper organising principle; whereby other symmetries assume the role of scale invariance.

A second major thread in my work concerns **quantum entanglement**. This is one of the foundational features of quantum systems, in which different parts of a system are deeply correlated. The classic example involves two parties, call them Alice and Bob, who each hold one part of an entangled state. These could be, for instance, spins or particles whose internal degrees of freedom are correlated in such a way that measuring one immediately gives information about the other, no matter how far apart they are. This non-classical correlation plays a crucial role in **quantum information, quantum computation**, and more recently also in understanding the **structure of spacetime** itself.

## Gravitation, string theory and cosmology group

### Stathis Vitouladitis

What I am interested in is **how entanglement interacts with symmetry**. One main question is whether a given quantum state is going to preserve a symmetry or break it. From the perspective of quantum information, this becomes a resource: symmetry-breaking states can store more information. Then, a quantitative measure of symmetry breaking is the entropy associated with how much information a state can hold, by virtue of symmetry breaking. This goes by the name of **entanglement asymmetry**[4]. Curiously, this quantity predicts a counter-intuitive effect, now observed in experiment[5], governing how quickly out-of-equilibrium systems return to equilibrium.

Until recently, entanglement asymmetry was mostly explored in lattice systems, with just a few applications in field theory. Together with collaborators, I extended it to generalised symmetries, as described above, and applied it to QFT[6]. The results were unexpectedly sharp. For example, entanglement asymmetry captures known theorems like Coleman–Mermin–Wagner, which states that **continuous symmetries cannot break spontaneously in low dimensions**.[1] More remarkably, such features can be read off without having access to all of the degrees of freedom: a **subsystem is sufficient**. This is especially handy in gravitational setups, where parts of the universe tend to be hidden, inconveniently behind horizons, as is for instance, **the interior of a black hole**.

Even more, we showed that entanglement asymmetry **counts Goldstone modes**, the massless particles which arise whenever symmetries are spontaneously broken - and tracks the **energy scale at which symmetry is restored**. These features make it a promising tool for probing thorny questions, like the **confinement of quarks**, where symmetries are known to play a role, but the precise mechanism remains poorly understood.

[1] Of course, we most likely live in three space and one-time dimensions, but quantum systems can be built to effectively live in lower dimensions, for instance a setup involving electrons constrained to move on a flat surface.

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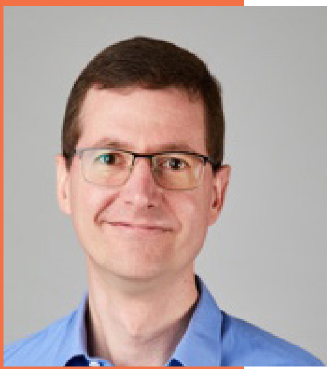


## Ben Craps
Professor - VUB


### *Quantum Complexity and Black Holes*

More than 50 years ago, intriguing parallels were discovered between certain properties of black holes and the laws of thermodynamics. Under this analogy, the area of a black hole horizon corresponds to entropy, and the surface gravity to temperature. Hawking demonstrated that this thermodynamic interpretation is physically meaningful because, quantum mechanically, black holes emit thermal radiation like a black body. The usual statistical underpinning of thermodynamics prompts the question of whether black hole entropy can be given a statistical interpretation in terms of counting black hole microstates. More recently, it has been proposed that the size of black hole interiors corresponds to quantum complexity, prompting a broad investigation into this concept, extending well beyond black hole physics. In what follows, we describe further background and some of our own contributions to these investigations.

Returning to the question of entropy, it is sometimes argued that the existence of black hole microstates is in tension with "no-hair theorems". These state that black hole solutions are characterized by a small number of charges, making it appear difficult to find enough microstate geometries to account for the entropy. However, these no-hair theorems only constrain black hole spacetimes outside their horizon and are perfectly compatible with having many different geometries behind the horizon for a given exterior geometry. Recent work by Balasubramanian, Lawrence, Magan, and Sasieta used thin shells of matter behind a black hole horizon to construct an infinite number of microstate geometries for the same exterior black hole spacetime. At first glance, this construction yields too many rather than too few states to account for the black hole entropy. Their key observation, however, was that certain non-perturbative contributions to the gravitational path integral lead to tiny overlaps between these microstates, causing them to span a finite-dimensional space with exactly the right dimension to explain the black hole entropy. In contrast to earlier explanations of black hole entropy in string theory, which were restricted to very special black holes, this new approach is applicable to much broader classes of black holes.

# Gravitation, string theory and cosmology group

## Ben Craps

Just over a decade ago, Susskind highlighted another geometric property of black holes, namely, that the size of their interiors keeps growing without bound in General Relativity. To what property of the quantum state of a black hole does this interior size correspond? Susskind proposed that it represents the quantum complexity of the black hole state — but defining and computing such complexity is far from straightforward. Quantum circuit complexity counts the minimal number of elementary operations ("gates") needed to create a given state from a reference state to a desired accuracy. Due to the arbitrary choices involved and the challenges of applying this notion to quantum field theories, it is not obvious how to relate circuit complexity to the size of black hole interiors.

Approximately two decades ago, Nielsen introduced a geometric notion of complexity that was designed to mimic circuit complexity while facilitating the application of differential geometry. The Nielsen complexity of a unitary operator is the minimal length of a curve in the manifold of unitaries connecting the identity operator to the target operator. To achieve the desired correspondence with circuit complexity, one needs to introduce a metric on the manifold of unitaries that encourages certain "easy" directions while penalizing "hard" directions, with the "easy" directions playing the role of elementary gates. Intuitively, this metric assigns a higher cost to "difficult" operations, just as circuit complexity does. While conceptually attractive, Nielsen complexity presents a significant drawback: it is practically impossible to compute for all but the simplest physical systems. This poses a fundamental challenge, quite apart from its potential applications to black holes.

Introduced in 2018, a distinct notion of complexity emerged from ideas in quantum chaos. Krylov complexity describes how a Hermitian "seed" operator spreads in the space of operators under Heisenberg time evolution. Alternatively, Krylov state complexity, also known as spread complexity, quantifies the spreading of a quantum state under time evolution. A priori, the spreading of operators and states is basis-dependent; Krylov complexity utilizes the specific basis that minimizes this spread.

For finite-dimensional Hilbert spaces, both Nielsen and Krylov complexity are expected to saturate at late times. An interesting question is whether the saturation value distinguishes between chaotic and integrable dynamics. Intuitively, one would expect chaotic time evolution to be more complex. However, demonstrating this has proven difficult because Nielsen complexity is computationally prohibitive, while Krylov complexity results heavily depend on the choice of the seed operator.

Recent work provides the first concrete realization of Susskind's proposal that the size of black hole interiors is related to quantum complexity: specifically, in 2d gravity models, the spread complexity of thermofield double states describing black holes equals the size of their corresponding interiors.

***These developments motivated the central research questions of our work:***

- How can Nielsen complexity be efficiently computed?
- Can complexity reliably distinguish between chaotic and integrable evolution?
- What is the precise relationship between Nielsen and Krylov complexity?
- Does the correspondence between complexity and black-hole interior size extend beyond 2d gravity models?

In[1,2], we constructed a computable upper bound on Nielsen complexity by minimizing over an infinite subset of curves instead of overall curves with specified endpoints. We demonstrated that this bound successfully distinguishes between chaotic and integrable time evolution by assigning higher saturation values to chaotic systems. Crucially, this upper bound can be expressed in terms of a "Q-matrix", which depends on the energy eigenstates and the choice of "easy" directions. Local conservation laws of a finite-dimensional Hamiltonian correspond to zero modes of this Q-matrix, where the chosen notion of locality defines the "easy" directions. This correspondence provides a constructive algorithm to find local conservation laws if they exist. Local conservation laws are a defining feature of quantum integrability, and we showed that they directly underlie the reduction of our bound-on Nielsen complexity for integrable systems.

As a probe of dynamics, Krylov complexity has two drawbacks. First, it assigns higher saturation values to chaotic dynamics than to integrable dynamics for some seed operators but not for others. Second, if one wants to probe the complexity of Hamiltonian evolution, it is conceptually unsatisfactory that one has to choose a seed operator. To remedy these shortcomings, in[3] we introduced multiseed Krylov complexity. Instead of relying on a single seed operator, this approach takes the space of all simple operators as its starting point. Consequently, one only needs to define a notion of "simplicity" — a requirement shared by other complexity measures. For the models tested, multiseed Krylov complexity outperforms the standard approach by reliably assigning higher complexity to chaotic dynamics.

We found two relations between Nielsen and Krylov complexity. First, the plateau height of Krylov state complexity is the trace of the Q-matrix of Nielsen complexity with an appropriate penalty schedule[4]. Second, Krylov operator complexity of a Hermitian operator establishes an upper bound for the square of Nielsen complexity of associated "precursor" operators with suitable penalties. Evidence suggests this bound saturates to an equality for certain types of seed operators in broad classes of models[5]. Building upon recent work on black hole microstate counting using shell states, we demonstrated that shell states can also count the microstates of out-of-equilibrium black hole fluctuations[6].

In ongoing work, we aim to synthesize these recent developments in complexity and microstate counting. By investigating avenues to extend the precise correspondence between complexity and size of black hole interiors beyond 2d gravity, and by exploiting structural similarities between Krylov complexity and properties of shell states, we aim to uncover the precise mechanisms linking quantum complexity to the geometry of black hole interiors and to black hole entropy.

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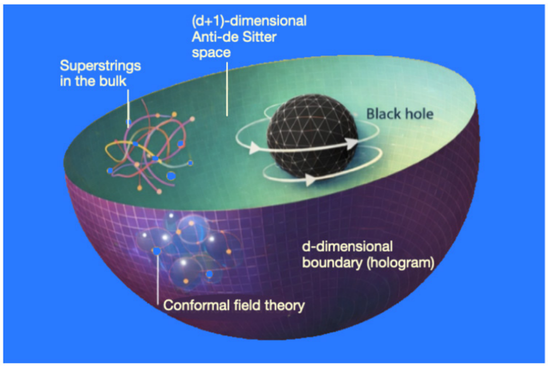
## Gravitation, string theory and cosmology group

### Chiara Toldo
**Faculty Member - ULB**

Black holes are compact celestial objects formed upon the collapse of very massive stars. In 1916 Karl Schwarzschild predicted their existence by solving Einstein's equations of General Relativity. A hundred years later, the LIGO/Virgo collaboration detected the merger of two such objects, confirming their existence in our universe. Black holes are among the most intriguing objects in theoretical physics: they radiate and possess entropy proportional to the area of their event horizon, suggesting that they are thermodynamic ensembles. The thermodynamic entropy has a statistical interpretation in terms of counting microscopic configurations with the same macroscopic properties: black hole entropy counts the constituents inside a black hole. Classical General Relativity is unable to predict the microscopic structure of the black hole interior, where the gravitational force reaches unparalleled strength. In this regime a theory of quantum gravity, unifying General Relativity and Quantum Mechanics, is needed. The formulation of such a theory is still one of the outstanding problems in modern physics.

A major obstacle so far has been the lack of concrete models to test theoretical ideas about the quantum behavior of gravity: my research aims at using analytically calculable models of black holes as a theoretical laboratory to address these fundamental issues. In my investigations, I mostly use the framework of String Theory and the holographic (AdS/CFT) correspondence, which states the equivalence of gravitational theories on curved spaces (Anti-de Sitter) and particular field theories (conformal field theories, CFTs) in one dimension less. Indeed, one of the advantages of the AdS/CFT correspondence is that it is a weak/strong duality: in other words, it allows a more tractable dual description for many physical systems. Quantities like black hole entropy have a clearer interpretation in the dual picture, by counting states living in this dual field theory without gravity. This has led to many advances in our understanding of the fundamental degrees of gravity in controlled, highly idealized gravitational setups. One of the aims of the research that I carry out with my MISU appointment at ULB is to make these computations more relevant for realistic black hole scenarios.

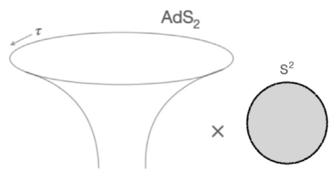



Progress in understanding the microscopic states inside black holes has been made possible thanks to the presence of an additional symmetry, called supersymmetry. This symmetry links two kinds of particles, bosons and fermions, and makes the computations much easier to carry out. In particular, it protects some physical quantities from being changed by complicated quantum effects, allowing physicists to compute them reliably.

Realistic black holes however break supersymmetry, and extending the results obtained in the supersymmetric setup is no easy task. Over the last years new breakthroughs have been obtained via the development of specific computational techniques can be applied to supersymmetry-breaking black holes in the so-called "near-extremal" regime. This is the regime where the black hole temperature is small, but non-zero. For a rotating black hole, the near-extremal regime means that the black hole is spinning very close to the maximum speed allowed by General Relativity, but not exactly at that limit. Very interestingly, this seems to be a physically relevant case, because black holes in our universe are believed to rotate very fast.

Understanding the physics of near-extremal black holes entails understanding the physics of two-dimensional Anti-de-Sitter spacetime ($AdS_2$), since their near-horizon region approximates AdS2. Standard holographic methods break down in this setting, as conformal symmetry in AdS2 forbids finite-energy excitations of a theory defined on it.

Recent studies however have shown that two-dimensional gravitational theory living on a background that approximates AdS2 (Jackiw-Teitelboim gravity) is dual to a one-dimensional nearly conformal quantum theory (Sachdev-Ye-Kitaev model). Both theories exhibit an interesting pattern of symmetry breaking and chaotic behavior in correlation functions and this duality goes under the name of near-$AdS_2$/near-$CFT_1$ holography.



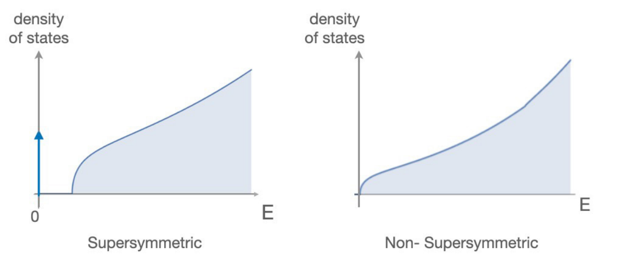

The near horizon geometry of an extremal black hole contains an $AdS_2$ space. JT gravity theories describe excitations over $AdS_2$ spacetimes

One important feature of models of JT gravity is that they are solvable, and allow a reliable computation for the quantum corrections that affect black hole thermodynamics. The research I carry out uses techniques from microstate counting for AdS black holes and near-AdS2 holography, bridging between them, to understand the microstructure of realistic rotating black holes. In my recent work we used the JT gravity theory appearing in the near-extremal horizon geometry of the black hole to reliably compute certain physical quantities relevant for black hole thermodynamics. This framework helps avoid certain technical problems (divergences) that appear when studying the region very close to the black hole's horizon. Using this approach, we were able to calculate how quantum effects modify the entropy of several types of rotating black holes, and give a precise expression for the density of states inside a black hole. In future work, I plan to investigate how processes that extract energy from a rotating black hole (superradiance) can influence these microscopic properties. The symmetries of the near-ring region for rotating near-extremal black holes and the photon trajectories will be investigated as well, since they relate to the observational predictions for the photon ring fine structure around the M87* black hole.

# Gravitation, string theory and cosmology group

## Chiara Toldo

One important feature of models of JT gravity is that they are solvable, and allow a reliable computation for the quantum corrections that affect black hole thermodynamics. The research I carry out uses techniques from microstate counting for AdS black holes and near-AdS2 holography, bridging between them, to understand the microstructure of realistic rotating black holes. In my recent work we used the JT gravity theory appearing in the near-extremal horizon geometry of the black hole to reliably compute certain physical quantities relevant for black hole thermodynamics. This framework helps avoid certain technical problems (divergences) that appear when studying the region very close to the black hole's horizon. Using this approach, we were able to calculate how quantum effects modify the entropy of several types of rotating black holes, and give a precise expression for the density of states inside a black hole. In future work, I plan to investigate how processes that extract energy from a rotating black hole (superradiance) can influence these microscopic properties. The symmetries of the near-ring region for rotating near-extremal black holes and the photon trajectories will be investigated as well, since they relate to the observational predictions for the photon ring fine structure around the M87* black hole.




Density of black hole states as a function of the energy E for supersymmetric setups (left): the number of distinct lowest-energy states (ground state degeneracy) is very large, indicated by the blue arrow, and there is a gap in the density. For non-supersymmetric systems (right) there is no ground state degeneracy and the density is a continuum.

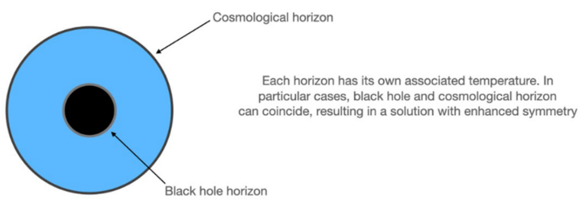
Other fundamental aspects of black holes physics are also taken into consideration in my research, in particular the possibility of deforming the shape of the event horizon. By studying the thermodynamics of these deformed solutions, one can detect various instabilities and model new phenomena in the dual field theory. This part includes for instance using various approximations and techniques to construct new black hole solutions such as Black Saturns, black rings, "Grey Galaxies" (mixtures of black holes and gravitons), and comparing their microscopic description, studying universal and non-universal aspects of black hole thermodynamics and horizons.

Lastly, some of my studies are devoted to quantifying the imprint of the environment in which the black hole lives on its thermodynamics, focusing especially on de Sitter black holes, due to their relevance for cosmology. Indeed, measurements of distant supernovae, the cosmic microwave background, and galaxy distributions show that the expansion of the universe is accelerating and the simplest explanation is the presence of a positive cosmological constant (or dark energy). A universe dominated by a positive cosmological constant approaches the geometry of de Sitter space.

de Sitter black holes are bound in size by the presence of a cosmological horizon, and the interplay of black hole and cosmological horizons introduces distinctive thermodynamic behavior, including a peculiar temperature dependence of the specific heat. The microscopic description is challenging because the system is not in equilibrium (the temperature of the cosmological horizon in general differs from the black hole one), and this can naturally generate a thermodynamic instability. Interestingly, a positive cosmological constant yields a very precise imprint on the various (near-)extremal black hole limits: there exist three different extremal limits, and the solutions are dubbed Cold, Nariai and Ultracold, and are characterized by different near horizon geometries – containing two-dimensional

Anti-de Sitter ($AdS_2$), de Sitter ($dS_2$) and flat ($Mink_2$) spaces, respectively.

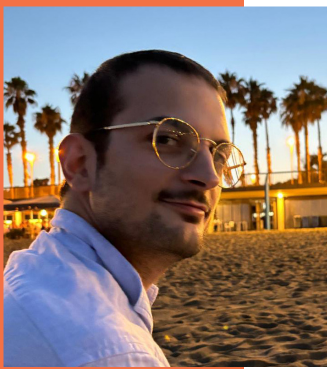
For these configurations, near-extremal holography and JT gravity represent a viable way to obtain a new window on the quantum and holographic properties of de Sitter space. My collaboration studied the near-extremal quantum corrections in the three different cases, highlighting in particular certain pathologies (negative norm states) that affect the Nariai configuration.




The quantum thermodynamics of the zero-temperature branch dubbed "ultracold" configuration, which has Mink2 near horizon geometry, deserved a separate treatment because it exhibits a very peculiar response and symmetry breaking pattern when the temperature is raised infinitesimally. With my collaborators we are developing a particular limiting procedure to compute its quantum corrected density of states, making use of the underlying BMS2 symmetry algebra. This setup is a good toy model for investigating the interplay between chaos and 2d flat holography.

Success on all these interconnected fronts gives fundamental insights into the building blocks of black holes and the degrees of freedom of quantum gravity. Crucial ingredients for black hole microstate investigations are the computation of supersymmetric partition functions and recent nAdS2 methods that turn gravitational dynamics into a quantum-mechanical boundary problem, the latter also relevant for chaotic systems.

## Gravitation, string theory and cosmology group



Giovanni Galati
Doctoral Researcher - ULB

*Extended probes in quantum physics*

Quantum Field Theory (QFT) currently stands as the most powerful and comprehensive framework physicists have developed to describe reality. It was originally created from the need to consistently incorporate Einstein's special relativity into the principles of quantum mechanics, leading to a profound shift in our understanding of nature. Within QFT, the fundamental entities are not particles but quantum fields, whose excitations manifest as particles.

One of the most successful theories formulated within this framework is the Standard Model of particle physics, which accurately describes the interactions among elementary particles such as electrons and quarks. Beyond high-energy physics, however, QFT also provides a unifying language for understanding universal phenomena that emerge at long distances and low energies. Notable examples include superconductors, superfluids, and insulating phases of matter, and it has a wide range of applications to various areas of science.

Given its broad applicability, QFT has remained a central focus of theoretical research. Over the years, physicists have devoted significant effort to uncovering general principles and systematic methods for solving quantum field theories and extracting predictive, physically measurable observables from them. Among the most extensively studied observables are correlation functions of local operators that measure the response of the system to local perturbations happening at specific points in space-time. In high-energy physics, such correlation functions can be used to determine the spectrum of particles and to compute cross sections of scattering processes, deriving predictions that can be measured in particle accelerators. In the condensed matter context, they crucially probe various phases of matter and can determine if a given system flows to criticality, i.e., in a phase where the correlation length diverges and conformal symmetry emerges, or to a gapped phase where all the excitations are massive.

However, in recent years it was appreciated that local operators and their correlation functions are not the only relevant observables one can compute. One may also consider operators supported on extended regions of spacetime. Famous examples include Wilson loop and 't Hooft loop operators in gauge theories, which play a central role in our understanding of confinement, or pinning line defects in Conformal

Field Theories (CFT) describing localized impurities of a material at criticality. Correlation functions of extended operators therefore provide access to more refined and subtle information about QFTs. While correlation functions of local operators can determine whether a system is gapped or gapless, extended operators can probe more intricate properties. For example, they can diagnose whether a phase exhibits topological order, an aspect of quantum matter that is invisible to purely local probes and requires genuinely non-local observables for its characterization.

Extended operators open a much wider window onto the non-perturbative structure of quantum field theory. Their study provides access to physical phenomena that are often invisible in a purely local or perturbative description. For this reason, a significant effort in modern theoretical physics is devoted to clarifying their physical properties, classification, and dynamical implications. Broadly speaking, one can distinguish three main families of extended operators:

1. **Topological Operators.**
2. **Conformal Defects.**
3. **Extended Excitations.**

**Topological Operators.** Topological operators are operators supported on extended regions whose properties depend only on the topology of their support rather than on its precise geometric shape. This means that they can be smoothly deformed in spacetime without affecting any correlation function, provided that they do not cross other operator insertions or wrap noncontractible cycles of the underlying manifold. Only such topologically nontrivial operations can modify the value of an observable. These operators have become central in modern theoretical physics because they offer a powerful and unifying perspective on symmetries in QFT. Symmetry principles are arguably the most fundamental guiding concept behind theoretical predictions in science, as they constrain the dynamics and organize physical phenomena. In recent years, it has been increasingly appreciated that, within the framework of QFT, symmetries can be naturally and systematically formulated in terms of topological operators and their action on the space of operators. For instance, an ordinary global symmetry acting on local operators can be understood as being generated by a codimension-one topological operator, that is, an operator supported on a (d−1)-dimensional manifold in a d-dimensional spacetime. When such a topological operator surrounds a local operator, it effectively measures its charge and implements the corresponding symmetry transformation. In this way, symmetries acquire a geometric and operator-based characterization, which can be further generalized to encompass more exotic symmetry structures beyond the traditional framework. In particular, one can mathematically describe the set of topological operators, and hence symmetries, using the language of category theory. Moreover, such geometric interpretation of symmetries gives us access to more refined properties which lead to non-perturbative constraints on QFTs. This is the case, for instance, of (generalized) 't Hooft anomalies, detected by considering complicated geometric configurations of topological defects (see Figure 1).

## Gravitation, string theory and cosmology group

Giovanni Galati

In the past few years, with the ULB group we have extensively investigated the consequences of such exotic symmetries on QFT, revealing how many non-perturbative aspects of QFT can be derived from symmetry principles. For instance, in collaboration with J. A. Damia and L. Tizzano, we studied Quantum Chromodynamics in 1+1 dimensions with adjoint matter. In this case we argued how the presence of highly non-trivial symmetries can be used to infer properties of the theory related to confinement. With R. Argurio, A. Collinucci, O. Hulik and E. Paznokas we have shown how certain families of CFTs related by marginal deformations, dubbed conformal manifolds, can be entirely derived by exploring the symmetry structure of a given theory and explore exotic manipulations one can perform with these symmetries. Many other applications have been explored in the recent past and a lot of exciting new results are now ready to be discovered using this new tool of generalized symmetries. Stay tuned!

**Conformal Defects.** These are extended operators supported on submanifolds of a system at criticality (i.e. a CFT), preserving the maximal subgroup of conformal symmetry compatible with their geometry. They are experimentally relevant, as they encode universal properties of materials with localized impurities.

Crucially, they also arise as the universal infrared description of quantum many-body systems, namely theories defined on higher-dimensional lattices that model particle or atomic distributions in a material. In this setting, impurities correspond to local modifications of the Hamiltonian acting on single lattice sites or small regions (see Figure 2). Remarkably, the framework of CFT and conformal defects provides an effective description of the behavior of such systems at criticality. The study of conformal defects has recently attracted renewed interest thanks to the development of new theoretical tools, including the conformal bootstrap, semiclassical methods such as large-charge and large-N expansions, and, more recently, the framework of generalized symmetries. In collaboration with A. Antinucci, C. Copetti, and G. Rizi, we explored the non-perturbative constraints that emerge from the interplay between conformal and topological defects, uncovering a broad landscape of new consistency conditions. A notable example is given by defect 't Hooft anomalies, namely anomalies localized on the defect that are absent in the bulk theory. The interplay between conformal and topological defects clarifies how the higher structure of a quantum field theory, encoded in the intricate network of intersections among its extended operators, can point toward new classes of observables that remain to be uncovered.

Extended Excitations. These are extended operators creating dynamical states when acting on the vacuum of a given theory. Notable examples include flux tubes in confining gauge theories and localized magnetic flux configurations in four–dimensional superconductors. They are probably the most exciting yet mysterious objects in QFTs. For instance, the spectrum of mesons and hadrons in the real world is believed to be described by such flux tubes and their interactions. Moreover, such objects are ubiquitous in String Theory, where they describe dynamical states called branes. In the past years researchers have developed techniques to study the dynamics of such objects in a systematic way.

For instance, Effective String Theory describes the dynamics of long and localized flux tubes embedded in a trivially gapped bulk. Notably, EST accurately describes the dynamics of QCD strings, i.e., chromodynamic flux tubes of the real world. In collaboration with J. A. Damia, G. Rizi and L. Tizzano we investigated the physics of confining flux tubes in 2 and 4 dimensions, focusing on gauge theories enjoying one-form symmetries, i.e., codimension 2 topological operators acting on line operators.

Again, we emphasize how the interplay between these exotic extended operators and the generalized symmetries can shed light on the dynamics of confining gauge theories.

To summarize, we have seen how the structure of Quantum Field Theories is far richer than was originally expected in the early years of their development. These theories, in fact, possess a wide spectrum of extended operators, each with distinct properties and physical implications. More importantly, understanding the interplay among them provides a deeper and more unified perspective on the theory itself, opening the way to new insights and connections.

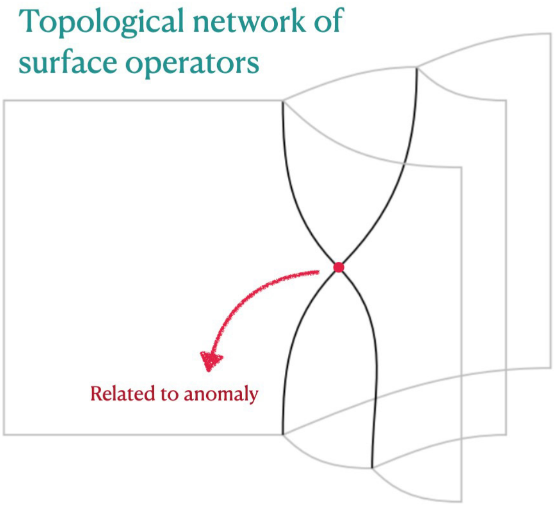



Figure 1: a network of topological operators intersecting in various subregions. Point-like junctions can detect anomalies of the corresponding symmetry

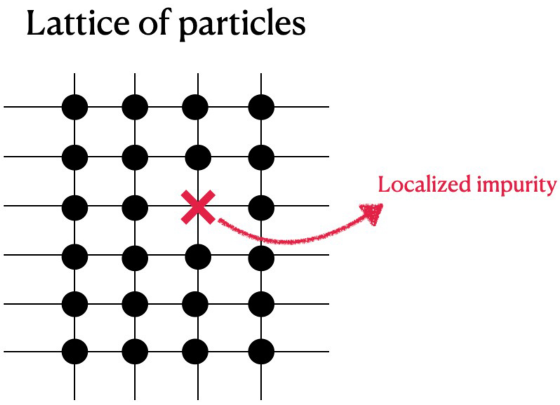



Figure 2: A 2d lattice model with an impurity localized on a site. At criticality, this impurity is described a line operator

## Gravitation, string theory and cosmology group


### Aäron Rasei
Doctoral Researcher - ULB


Ever since humans began roaming the Earth, they have wondered what lies beyond our world. Gazing into the night sky with the naked eye, one can see the flickering light of distant stars, the bright glow of the Moon, and the brief streak of a falling star. Today, telescopes operating across the entire electromagnetic spectrum enable us to observe galaxies billions of light-years away and even detect radiation emitted approximately 380,000 years after the Big Bang, known as the Cosmic Microwave Background (CMB). These observations have shaped our understanding of the early Universe and the processes that led to its structure as we see it today.

Beyond electromagnetic observations, a completely new way of exploring the Universe emerged in 2015 with the first direct detection of gravitational waves (GWs) by the LIGO-Virgo-KAGRA (LVK) collaboration. These waves, first predicted in 1916 by Albert Einstein's theory of General Relativity, are ripples in the fabric of spacetime that travel at the speed of light. Because gravity is so weak, GWs interact only minimally with matter and radiation, allowing them to propagate essentially unimpeded from the moment of their production. As a result, they carry largely unaltered information about the processes that generated them and the state of the Universe at the time of emission. GWs therefore offer a completely new window into the history and evolution of the Universe, reaching epochs that are otherwise inaccessible, even beyond the era of the CMB.

Strong GW signals can arise from nearby astrophysical systems, such as binary black hole mergers (as was the case for the first detection), core-collapse supernovae, or rapidly rotating neutron stars with slight asymmetries in their shape. However, for sources that are too distant or too faint to be individually resolved, their weak GWs overlap and combine to form a random, noise-like background known as the gravitational-wave background (GWB). Much like an orchestra composed of different instrumental "populations" performing a symphony, the GWB presents a complex overall sound. As the audience, we can attempt to disentangle the contributions of each instrumental section and identify their individual characteristics. For instance, we might notice that only two bassoons are playing, or that the violins are underperforming in certain passages. The richness of information contained within this symphony cannot be underestimated. Similarly, the GWB carries detailed information about the populations and mechanisms that generate it, providing a unique window into astrophysical processes that are otherwise difficult to observe.

In addition to astrophysical sources, the GWB can also include contributions from cosmological processes in the very early Universe, potentially originating shortly after the Big Bang. These may include GWs generated during inflation, from primordial black holes, first-order phase transitions, or topological defects. Such phenomena arise in Beyond the Standard Model (BSM) physics scenarios, and the detection of a cosmological GWB could therefore be considered a pinnacle of GW astronomy, offering profound insights into high-energy physics that would otherwise remain inaccessible to terrestrial collider experiments.

In my work, I focus on a particular type of topological defect: domain walls (DWs). In general, topological defects arise during phase transitions, when a symmetry is spontaneously broken as the Universe cools due to its expansion. This can be understood by analogy with water freezing into ice: the liquid phase is highly symmetric, as its molecules are randomly distributed and the system looks the same in every direction. However, as water freezes, the crystal structure of ice selects preferred directions, thereby breaking the original symmetry. Freezing occurs independently in different regions, and when growing ice crystals meet, mismatches in their orientations give rise to visible lines or "defects" at their boundaries. Similarly, in the Universe, spontaneous symmetry breaking produces uncorrelated regions, with topological defects forming at the boundaries between them.

In the context of DWs, a discrete symmetry within a scalar field theory is spontaneously broken. Distant regions of the Universe that are causally uncorrelated can settle into different vacuum states of the theory. At the boundaries between these regions, the scalar field must transition gradually from one state to the other. This localized transition forms a DW separating the two regions. Although these walls can be extremely thin, they can contain enormous amounts of energy, which can be radiated away in the form of GWs. In this way, DWs act like an instrument group in the cosmic symphony, contributing to the overall GWB.

After formation, the DW network enters a scaling regime in which the number of DWs per causally connected region is of order unity and the average velocity of the walls is mildly relativistic. During this regime, the energy density of the network decreases more slowly than that of the radiation and matter components of the Universe. Therefore, DWs would eventually dominate the Universe, leading to a faster expansion incompatible with cosmological observations. To avoid this problem, a mechanism must ensure the annihilation of these objects. This can be achieved by introducing a small bias that explicitly breaks the underlying discrete symmetry. In this way, one of the vacuum states is preferred and becomes the true vacuum, inducing a pressure force that causes the walls surrounding regions of false vacuum to shrink and eventually collapse.

With the first strong evidence of a GWB reported in 2023 by the Pulsar Timing Array (PTA) consortium and the development of future third-generation GW experiments, GW astronomy is undergoing rapid progress. Accurately describing the GWB signal from all possible sources, including a DW network, is therefore increasingly important. In this context, I have been working on lattice field simulations to model the dynamics of DWs and extract the resulting GWB signal. In these simulations, a scalar field dynamically evolves within a finite box representing the expanding Universe. By tracking transitions of the scalar field from one vacuum state to another, DWs can be identified, their evolution followed, and their GW production quantified.

## Gravitation, string theory and cosmology group

### Aäron Rasei

This analysis is performed explicitly in the scaling regime, assuming that the DW network does not dominate the energy density of the Universe. In this regime, the GWB energy density spectrum, as a function of frequency, exhibits a broken power-law behavior. This result is consistent with simulations performed by other research groups, although quantitative differences remain. More accurate studies of the collapse phase are still required, as discrepancies between simulations indicate that the impact of DW annihilation on the resulting GW spectrum is not yet fully understood.

As the DW network propagates through the hot cosmic plasma, friction effects caused by particles interacting with the walls are inevitable. I have investigated these effects specifically for axion DWs, studying how they modify the resulting GWB signal. These results were even used to interpret the aforementioned strong evidence reported by the PTA, with future observations expected to clarify whether this signal indeed originated from a DW network.

In addition, searches for the broken power-law GWB spectrum can be performed in LVK data. As a member of the LVK collaboration, I investigated whether a GWB signal from a DW network was present during the fourth observation run. No signal was observed, resulting in bounds on phenomenological parameters describing the DW network, such as their tension and the time of annihilation. These constraints are particularly relevant for BSM physics models where DWs arise, as they can be used to rule out certain scenarios. Indeed, DWs appear in several BSM scenarios and play a key role in other early-Universe processes. For example, DWs can contribute to the formation of primordial black holes through network collapse, the generation of the baryon asymmetry, and the production of dark matter, among other phenomena. It is clear that the observation of a GWB signal from a DW network would revolutionize our understanding of both the evolution of the early Universe and the high-energy physics underlying these processes. With future observatories underway, the outlook is as bright as the night sky humans have long gazed upon, and perhaps one day we might even hear the cosmic "melody" of cracks in the primordial ice.

# Achievements & Awards

**Maxime Grandjean** obtained an FWO "aspirant" PhD fellowship, Gabriele Pascuzzi obtained a renewal of his aspirant PhD fellowship.

**Shan-Ming Ruan** was selected for a prestigious FWO senior postdoctoral fellowship but turned it down for a faculty position at Peking University.

**Ben Craps** and **Vijay Balasubramanian** were awarded an FWO senior research project "Spread complexity and the size of black hole interiors in quantum gravity" and Alexander Sevrin obtained a major FWO International Research Infrastructure (IRI) project "ET-TECH: Empowering Tomorrow's Technological Horizons for Einstein Telescope".

## Theses defended in 2025

**José Figueroa Silva**: "Symmetries in gravity: from AdS to flat space and back" - 5 September 2025
Thesis advisors: Prof. S. Detournay, ULB & J. Oliva, Concepción

**Romain Vandepopeliere**: "Global Aspects of Strongly-Coupled Gauge Theories" - 23 May 2025
Thesis advisor: Prof. R. Argurio, ULB

## Gravitation, string theory and cosmology group

### Talks at conferences, seminars and schools

#### Adrien Arbalestrier

***Gauging, Continuous TQFTs, and Higher Symmetry Structures***
University of Murcia, Murcia, Spain
13 May 2025

#### Riccardo Argurio

***Continuous TQFTs & non-invertible symmetries***
***String Theory as a Bridge between Gauge Theory and Quantum Gravity***
Sapienza University of Rome, Italy
19 February 2025

***Quantum Field Theory and Symmetry: a Generalized (and Non-Invertible) Story***
Max Planck Institute for Gravitational Physics, Potsdam, Germany
29 October 2025

***4d Maxwell on the Edge: Global Aspects of Boundary Conditions and Duality***
Seminar of the Physics Department - Università di Firenze, Italy
19 November 2025

#### Glenn Barnich

***Model spaces as constrained systems***
HolographyCL Farewell Meeting School & Workshop
Universidad Adolfo Ibáñez, Viña del Mar, Chile
13 & 14 January 2025

***Lessons from DCLCQ for gravity at null infinity***
HolographyCL Farewell Meeting School & Workshop
Universidad Adolfo Ibáñez, Viña del Mar, Chile
17 January 2025

***Model spaces as constrained Hamiltonian systems I. Application to SU(2)***

- Institut Mittag-Leffler, Stockholm, Sweden
  31 March 2025

- University of Vienna, Austria
  03 April 2025

- Albert Einstein Institute, Golm, Germany
  07 July 2025

- University of Jena, Germany
  30 September 2025

***AdS/CFT meets Carrollian & Celestial Holography***
International Centre for Mathematical Sciences, Edinburgh, UK
09 November 2025

***Effet mémoire des ondes de Robinson et Trautman***
Congrès de la SMF 2025
Université de Bourgogne, Dijon, France
06 April 2025

***Memory of Robinson-Trautman waves***

- Simons Celestial Holography Annual Meeting & Satellite Meeting
  Simons Foundation, New York, USA
  15 April 2025

- Institut Camille Jordan, Université de Lyon, France
  23 May 2025

- Holography in & beyond the AdS paradigm
  University of Montevideo, Uruguay
  5 June 2025

- GGI Conference on Asymptotic Symmetries and Flat Holography
  Galileo Galilei Institute, Florence, Italy
  6 October 2025

- Albert Einstein Institute, Golm, Germany
  28 October 2025

## Andrés Collinucci

***Calabi–Yau manifolds***
Pollica Physics Centre, Pollica,
Italy
3 June 2025

## Gravitation, string theory and cosmology group

### Talks at conferences, seminars and schools

#### Andrés Collinucci

*Fields and Strings Theory Seminar*
LMU, Munich, Germany
20 December 2025

*String Theory Seminar*
Birmingham University, UK
20 October 2025

#### Geoffrey Compère

*Comprendre, voir et entendre les trous noirs*
Présentation aux rhétos (secondaires)
Ecole Saint-Hubert, Brussels, Belgium
27 May 2025

*Hybrid post-Newtonian/self-force inspiral & transition-to-plunge waveforms*
Mathematical Methods for the General Relativistic Two-body Problem
Institute for Mathematical Sciences of the National University of Singapore
12 August 2025

*Hybrid self-force/PN waveform models for quasi-circular inspirals*
Compact Binary Coalescence (CBC) Waveform Call
The Virgo Collaboration - Online
25 September 2025

*SciPost: 10 years of Diamant journal*
Webinaire "Open Access Diamant"
ULB - Online
24 October 2025

*High-precision gravitational waveforms: combining self-force and post-Newtonian theories*
IRCHEP 1404 Iranian conference on High Energy Physics
Institute for Research in Fundamental Sciences (IPM, Tehran, Iran)
2 December 2025

## Emilie Despontin

*Asymptotic Symmetries of pp-wave Spacetimes*
Holography, Strings and other fun things II
BITS Pilani, Goa, India
23 February 2025

*A Review on WZW Models and their Marginal Deformations*
ULB, Brussels, Belgium
25 April 2025

*Asymptotic Symmetries of pp-wave Spacetimes (Poster Session)*
Eurostrings 2025 - Nordita, Stockholm, Sweden
25 August 2025

*Fun with (A)dS: one-loop corrections*
BLU-PandA - PhD Day
ULB, Brussels, Belgium
5 December 2025

## Stéphane Detournay

*Musings on the 3d black string: Asymptotic T-duality and Ttbar deformations*
Workshop on Black Holes, Holography and de Sitter
Milano University, Italy
13 January 2025

*A toy model for photon ring holography*
Workshop on Holography, Strings, and other fun things
Birla Institute of Technology and Science Pilani, Goa, India
12 to 19 February 2025

*Non-Lorentzian holography*
Workshop – AdS/CFT meets Carrollian & celestial holography
ICMS, Edinburgh, UK
8 to 12 September 2025

# Gravitation, string theory and cosmology group

## Talks at conferences, seminars and schools

### Frank Ferrari

*Random Disks of Constant Curvature and Jackiw-Teitelboim Quantum Gravity*

- Université Claude Bernard Lyon I, Institut Camille Jordan, France
  7 February 2025

- Institute for Advanced Study, Tsinghua University, Beijing, China
  16 April to 30 April 2025

*Random Disks of Constant Curvature: from strange metals to quantum gravity through black holes*
When the M meets the P
Université Catholique de Louvain (UCL), Louvain-la-Neuve, Belgium
19 May 2025

*Random Disks of Constant Curvature: holography, quantum gravity, combinatorics and probabilities*
Hyperbolic random planar geometry conference
CIRM (Centre International de Rencontres Mathématiques), Marseille, France
4 August 2025

*JT gravity on finite geometry: from finite cut-off holography to emerging time?*

- Huzhou University, Huzhou, China
  27 October 2025

- Jiao Tong University, Shanghai, China
  29 October 2025

- Westlake University, Institute for Theoretical Sciences, Hangzhou, China
  30 October 2025

- Huzhou University, Huzhou, China
  31 October 2025

*JT gravity on finite geometry*

- Mathematical Physics Seminar
  Yau Mathematical Sciences Center (YMSC), Tsinghua University, Beijing, China
  19 November 2025

- Mathematical Physics Seminar
  Beijing International Center for Mathematical Research (BICMR), Peking University, Beijing, China
  2 December 2025

- Shanghai Institute for Mathematics and Interdisciplinary Sciences (SIMIS), Shanghai, China
  3 December 2025

## José Figueroa Silva

***Covariant phase space and boundaries***
Open lectures at Universidad de Concepción
Universidad de Concepción, Concepción, Chile
10 January 2025

***Asymptotic T-duality in 3D (Poster Session)***
HolographyCL Farewell Meeting
Universidad Adolfo Ibañez, Viña del Mar, Chile
16 January 2025

***Asymptotic T-duality in 3D***
Holography, strings and other fun things 2
IIT Kanpur and BITS Goa, Goa, India
13 February 2025

***Asymptotic T-duality in 3D (Poster Session)***
GGI School on Asymptotic Symmetries and Flat Holography
Galileo Galilei Institute, Firenze, Italy
22 May 2025

## Dima Fontaine

***Bulk realisation of anisotropic conformal Carroll symmetries***

- Holography, strings and other fun things II
  IIT Kanpur & BITS Pilani, Goa, India
  17 February 2025

- Departmental journal club
  Institut Denis Poisson, Université de Tours, Tours, France
  9 October 2025

# Gravitation, string theory and cosmology group

## Talks at conferences, seminars and schools

### Dima Fontaine

*Bulk realisation of anisotropic conformal Carroll symmetries (Poster Session)*

- GGI School on Asymptotic Symmetries
  Galileo Galilei Institute, Florence, Italy
  21 May 2025

- The Holographic Universe
  KU Leuven, Leuven, Belgium
  2 June 2025

### Giovanni Galati

*Symmetries and Defects*
QFT in AdS: from BCFT to Confinement
IGAP, Trieste, Italy
12 February 2025

*Topological Constraints on Defect Dynamics*
Symmetry Seminar
Online seminar. Organized by Oxford
25 February 2025

*Flat Gauging, Compact Boson & T-Duality*
GCS Postdoc and Student Colloquium
Online seminar.
27 February 2025

*Topological Constraints on Defect Dynamics*
Recent advances in Quantum Field Theories
Sofia University, Sofia, Bulgaria
25 June 2025

*Recent progress in 2d gauge theories*
XXI Avogadro meeting
University of Catania, Catania, Italy
19 December 2025

## Marc Henneaux

*Matching conditions between past infinity and future infinity in asymptotically flat spaces*
2 one-hour and a half lectures at Summer School "HolographyCL Farewell Meeting"
Universidad Adolfo Ibáñez, Viña del Mar, Chile
13 to 15 January 2025

*Carroll swiftons*
Workshop "HolographyCL Farewell Meeting"
Universidad Adolfo Ibáñez, Viña del Mar, Chile
16 to 18 January 2025

*Carroll swiftons or how to construct Carroll-invariant field theories*
Instituto de Ciencias Exactas y Naturales (ICEN), Universidad Arturo Prat, Iquique, Chile
24 January 2025

*Ultrarelativistic Limits of Gravity and Carroll Group*
Università di Trento, Italy
11 February 2025

*Asymptotic symmetries in gauge theories with emphasis on gravity (Colloquium)*
Università di Trento, Italy
12 February 2025

*Carroll limit of gravity and spacelike singularities: BKL revisited*
Università di Trento, Italy
13 February 2025

*Matching conditions between past null infinity and future null infinity*
CBPF, Rio de Janeiro, Brazil
3 April 2025

*Asymptotic symmetries in gauge theories with emphasis on gravity (Colloquium)*
PUC, Rio de Janeiro, Brazil
3 April 2025

*The asymptotic structure of gravity (3 one-hour lectures)*
Summer School "Verão Quântico 2025" – Iriri, ES, Brazil
7 to 11 April 2025

*Asymptotic symmetries and algebras: a review with emphasis on gravity (Colloquium)*
Perimeter Institute, Waterloo, Canada
30 April 2025

## Gravitation, string theory and cosmology group

### Talks at conferences, seminars and schools

#### Marc Henneaux

*Carroll limit of gravity and spacelike (Belinski-Khalatnikov-Lifshitz) singularities*
Perimeter Institute, Waterloo, Canada
1 May 2025

*Matching conditions between past null infinity and future null infinity (online lecture)*
Beijing Institute of Mathematical Sciences and Applications, China
23 May 2025

*Wheeler-DeWitt equation and flat space holography (Vision talk)*
Workshop "AdS/CFT meets Carrollian & Celestial Holography"
ICMS, Bayes Centre, University of Edinburgh, UK
8 to 12 September 2025

*L'espace et le temps en physique*
Café "Science et Philosophie"
Astronef, Saint-Étienne, France
23 September 2025

*The Wheeler-DeWitt equation in asymptotically flat spaces (online lecture)*
International Centre for Theoretical Sciences (ICTS), Tata Institute of Fundamental Research, Bengaluru, India
6 October 2025

*The Wheeler-DeWitt equation and the BMS symmetry*
NYU, New York, USA
27 October 2025

*The Wheeler-DeWitt equation and the Bondi-Metzner-Sachs (BMS) symmetry*
University of Texas at Austin, USA
31 October 2025

#### Loïc Honet

*Hybridising self-force with post-Newtonian quantities*
Self-force group seminar
University of Southampton, UK
19 February 2025

*Hybrid waveform models for asymmetric compact binaries*
GR24 / Amaldi16
Scottish Event Campus, Glasgow, UK
16 July 2025

*Hybrid waveform models for spinning binaries*
Capra 28
University of Southampton, UK
23 July 2025

## Mario De Marco

*On 5d conformal matter*

- University of Milano-Bicocca, Milan, Italy
  8 January 2025

- Harvard CMSA (online talk)
  10 February 2025

*Quiver approach to non-compact CY3s*

- University of Birmingham, Birmingham, UK
  23 June 2025

- ICTP, Trieste, Italy
  08 September 2025)

*On the String Theory Realization of Discrete Gauging*
Durham University, Durham, UK
17 November 2025

## Kévin Nguyen

*Soft theorems and spontaneous symmetry breaking*
Workshop on asymptotic symmetries and flat holography
Galileo Galilei Institute, Florence, Italy
6 November 2025

# Gravitation, string theory and cosmology group

## Talks at conferences, seminars and schools

### Kévin Nguyen

*Hilbert space and Unitarity in celestial and carrollian holography*
AdS/CFT Meets Carrollian and Celestial Holography
International Centre for Mathematical Sciences, Edinburgh, UK
9 September 2025

*Progress in Carrollian Holography*
Utrecht University, Utrecht, The Netherlands
14 November 2025

### Gabriel Andres Piovano

*Gravitational waveforms from perturbation theory for LISA (and LIGO/Virgo/Kagra)*
Caltech, Los Angeles, United States
28 February 2025

*Spherical inspirals of spinning bodies into Kerr black holes*
28th Capra Meeting on Radiation Reaction
University of Southampton, Southampton, UK
24 July 2025

### Jakob Salzer

*Quantizing Carrollian Field Theories*

- From Asymptotic Symmetries to Flat Holography
  Galileo Galilei Institute, Florence, Italy
  5 June 2025

- All Lambda Holography Workshop
  Bogazici University, Istanbul, Turkey
  17 September 2025

*Detector Operators and Asymptotic Symmetries*
Würzburg University, Würzburg, Germany
9 December 2025

## Colin Sterckx

*How to uplift non-maximal gauged supergravities*
Séminaire AnLy (Ancy Lyon)
Annecy/Lyon, Online, France
26 November 2025

## Chiara Toldo

*Quantum corrections to near-extremal black hole entropy in de Sitter*
XV Workshop on Geometric Correspondences of Gauge Theories
ICTP, Trieste, Italy
16 June 2025

*Quantum corrections to near-extremal black hole thermodynamics*

- Corfu Summer Institute, Corfu, Greece
  09 December 2025

- ULB, Brussels, Belgium
  11 October 2025

*Thermodynamics of near-extreme rotating black holes*
Supergravity 2025 workshop
Turin Polytechnic University, Turin, Italy
17 September 2025

*Thermodynamics of near-extreme black holes*
Scuola Normale Superiore, Pisa, Italy
30 October 2025

*Lectures on Black holes & quantum gravity*
VI Siembra-HoLAGrav Young Frontiers Meeting at ICTP-SAIFR
ICTP Sao Paulo, Sao Paulo, Brazil
June 30 to July 11, 2025

# Gravitation, string theory and cosmology group

## Publications

### Papers published in 2025


[1] N. Afshordi et al. [LISA Consortium Waveform Working Group], "Waveform modelling for the Laser Interferometer Space Antenna," Living Rev. Rel. 28 (2025) no. 1, 9. doi:10.1007/s41114-025-00056-1 [arXiv:2311.01300 [gr-qc]].

[2] A. Aggarwal, A. Bagchi, S. Detournay, D. Grumiller, M. Riegler and J. Simon, "Universal sectors of two-dimensional Carrollian CFTs," JHEP 11 (2025), 039. doi:10.1007/JHEP11(2025)039 [arXiv:2508.05735 [hep-th]].

[3] S. Agrawal and K. Nguyen, "Soft theorems and spontaneous symmetry breaking," Phys. Rev. D 112 (2025) no. 2, L021903. [arXiv:2504.10577 [hep-th]].

[4] J. Aguilera Damia, R. Argurio, A. Bourget, V. Tatitscheff and R. Vandepopeliere, "Global variants of N = 1* theories and Calogero-Moser systems," JHEP 08 (2025), 212. doi:10.1007/JHEP08(2025)212 [arXiv:2504.01502 [hep-th]].

[5] J. Aguilera Damia, G. Galati and L. Tizzano, "Symmetries, universes and phases of QCD2 with an adjoint Dirac fermion," JHEP 12 (2025), 230. doi:10.1007/JHEP12(2024)230 [arXiv:2409.17989 [hep-th]].

[6] A. Antinucci, C. Copetti, G. Galati and G. Rizi, "Topological constraints on defect dynamics," Phys. Rev. D 111 (2025) no. 6, 065025. doi:10.1103/PhysRevD.111.065025 [arXiv:2412.18652 [hep-th]].

[7] A. Antinucci, C. Copetti, G. Galati and G. Rizi, "Defect Conformal Manifolds from Phantom Noninvertible Symmetries," Phys. Rev. Lett. 135 (2025) no. 21, 211602. [arXiv:2505.09668 [hep-th]].

[8] F. Aramini, R. Argurio, M. Bertolini, E. García-Valdecasas and P. Moroni, "Gravity, finite duality cascades and confinement," JHEP 09 (2025), 054. doi:10.1007/JHEP09(2025)054 [arXiv:2506.18988 [hep-th]].

[9] A. Arbalestrier, R. Argurio and L. Tizzano, "U(1) gauging, continuous TQFTs, and higher symmetry structures," SciPost Phys. 19 (2025) no. 2, 032. doi:10.21468/SciPostPhys.19.2.032 [arXiv:2502.12997 [hep-th]].

[10] R. Argurio, A. Collinucci, S. Mancani, S. Meynet, L. Mol and V. Tatitscheff, "Inherited non-invertible duality symmetries in quiver SCFTs," JHEP 06 (2025), 227. doi:10.1007/JHEP06(2025)227 [arXiv:2409.03694 [hep-th]].

[11] R. Argurio, A. Collinucci, G. Galati, O. Hulik and E. Paznokas, "Non-invertible T-duality at any radius via non-compact SymTFT," SciPost Phys. 18 (2025), 089. doi:10.21468/SciPostPhys.18.3.089 [arXiv:2409.11822 [hep-th]].

[12] G. Barnich and T. Smoes, "Model spaces as constrained Hamiltonian systems. Part I: Application to SU(2)," JHEP 10 (2025), 056. doi:10.1007/JHEP10(2025)056 [arXiv:2502.20267 [hep-th]].

[13] A. Bourget, A. Collinucci and S. Schäfer-Nameki, "Generalized Toric Polygons, T-branes, and 5d SCFTs," SciPost Phys. 18 (2025), 079. doi:10.21468/SciPostPhys.18.3.079 [arXiv:2301.05239 [hep-th]].

[14] S. Chakraborty, G. Compère and L. Machet, "Tidal Love numbers and quasinormal modes of the Schwarzschild-Hernquist black hole," Phys. Rev. D 112 (2025) no. 2, 024015. [arXiv:2412.14831 [gr-qc]].

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JHEP 01 (2025), 160. doi:10.1007/JHEP01(2025)160 [arXiv:2404.03748 [hep-th]].

[17] G. Compère, S. J. Hoque and E. Ş. Kutluk, "SO(1,4) flux-balance laws of de Sitter spacetime at quadrupolar order," Phys. Rev. D 111 (2025) no. 6, 064039. doi:10.1103/PhysRevD.111.064039 [arXiv:2411.16215 [gr-qc]].

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[20] M. De Marco, M. Del Zotto, J. F. Grimminger and A. Sangiovanni, "Remarks on the Higgs branch of 5d conformal matter," JHEP 10 (2025), 144. doi:10.1007/JHEP10(2025)144 [arXiv:2502.04431 [hep-th]].

[21] M. De Marco and S. N. Meynet, "Symmetries beyond branes: geometric engineering and isometries," JHEP 08 (2025), 082. doi:10.1007/JHEP08(2025)082 [arXiv:2503.19022 [hep-th]].

[22] E. Despontin, S. Detournay, S. Dutta and D. Fontaine, "Anisotropic conformal Carroll field theories and their gravity duals," JHEP 09 (2025), 056. doi:10.1007/JHEP09(2025)056 [arXiv:2505.23755 [hep-th]].

[23] S. Detournay, J. Figueroa Silva and A. Vilar López, "Asymptotic T-duality in three dimensions," SciPost Phys. 19 (2025) no. 2, 044. doi:10.21468/SciPostPhys.19.2.044 [arXiv:2412.16136 [hep-th]].

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## Research Summary

*"It is dissymmetry that creates phenomena"* is a famous citation from Pierre Curie.[1] In this vein, and more generally, our research group studies how the symmetry and symmetry breaking of chemical and physical systems affect their structure, dynamics, and properties. It is logical to say that physical and chemical phenomena cannot depend on how theory describes them. Therefore, their description must be insensitive to parity reversal (x, y, z becomes -x, -y, -z) and time reversal (t becomes -t). These conceptual tools form the basis of our thinking and prove fruitful for the study of polymorphism and isomorphism, for the development of absolute asymmetric synthesis, for understanding the link between particle helicity and molecular chirality, and also for better understanding the phenomena of heat, charge, and spin transport in organic semiconductors.

### Polymorphism & Isomorphism

Polymorphism, which is the existence of more than one crystalline phase for a given chemical compound, defies comprehension by chemists and physicists. It is characterized by a high degree of unpredictability that sometimes causes sleepless nights for manufacturers, particularly in the pharmaceutical sector, because the crystalline form of an active pharmaceutical ingredient determines its solubility and therefore its therapeutic efficacy. Ritonavir, an HIV protease inhibitor, is a particularly tragic case. During the summer of 1998, a sudden change in the solubility of this drug led to the cessation of its production and an interruption of treatment for millions of HIV-positive patients. The crystalline form of ritonavir had unexpectedly transformed into a less soluble polymorph. Our research group is trying to understand and grasp the stochastic nature of the emergence of new polymorphs, drawing on the work of Ilya Prigogine, who showed that chemical systems sufficiently far from thermodynamic equilibrium can bifurcate into new states following a compositional fluctuation. Building on this understanding, we intentionally maintain systems out of equilibrium and attempt to guide their evolution toward specific states using an external perturbation.[1,2] Initial results are encouraging, although our understanding is still in its early stages. Besides the experimental conditions of pressure, temperature, and composition that lead to the formation of polymorphs, polymorphism is also encoded in the molecular structure. This structure determines the number and relative thermodynamic stability of the polymorphs. Unfortunately, no one has yet been able to decipher this molecular code. We are trying to break it by studying model molecular systems and modifying them minimally to see how these modifications impact the formation of polymorphs. Current results, however, show a weak correlation between the number of polymorphs and the molecular structure. Through serendipity, we discovered a homologous series of five compounds, depicted in Figure 1, exhibiting isomorphic crystal structures, meaning they crystallize in the same form despite their different molecular structures.[3] This is the inverse of polymorphism. Fortunately, these five achiral compounds are forming conglomerates of enantiomorphic crystals, and are capable of reacting under the influence of light to form chiral molecules. These five compounds thus constitute ideal systems for the absolutely asymmetric synthesis discussed in the following section.

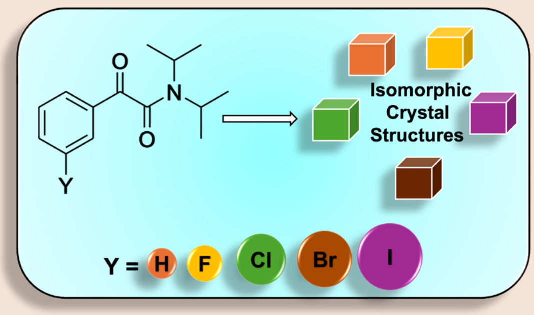


Figure 1. Homologous series of five molecules forming the isomorphic crystal structures, i.e., sharing the same space group and comparable crystallographic parameters.

## Absolute asymmetric synthesis

Chirality is a geometric property where an object or molecule is not superimposable on its mirror image, like a left hand and a right hand. Discovered by Louis Pasteur, chirality is crucial in chemistry and biology. The two enantiomers of a molecule can have different biological effects or odors. Chiral molecules rotate the plane of polarization of light either clockwise or counterclockwise. The former are called dextrorotatory and the latter levogyre. One of the major unresolved questions in chemistry is the origin of biohomochirality. All other living organisms share the characteristic of being composed of dextrorotatory sugars and levogyre amino acids. Two hypotheses have been formulated: either it is a matter of chance, or there is a physical cause that leads to this choice by nature. Absolute asymmetric synthesis is the production of an optically active chiral compound (pure enantiomer) from achiral precursors, without the intervention of chiral agents (reagents, catalysts, or solvents), but through the action of a physical cause such as circularly polarized light. Cases of absolute asymmetric synthesis are relatively rare.

My group used the molecules described in Figure 1 to perform absolute asymmetric syntheses, taking advantage of the fact that they crystallize as chiral crystals, also called enantiomorphs, which possess a chiral shape. These can be separated manually, as Louis Pasteur did with tartaric acid crystals.[1] The molecules adopt a chiral conformation within the crystals, which can be transformed into a chiral configuration by a photoinduced reaction, as shown in Figure 2. The reaction product is a molecule with an asymmetric carbon, that is, one possessing four different substituents. The enormous advantage of crystallization is that it amplifies a slight initial asymmetry, ultimately resulting in a crystal where all molecules possess the same chirality. It is therefore one of the most efficient mechanisms of chiral amplification. Such molecular systems are ideal for studying the influence of external physical causes on molecular chirality. Besides photons from circularly polarized light, other particles could have caused the biohomochirality of living organisms. This leads us naturally to the concept of helicity, which is developed in the next paragraph.

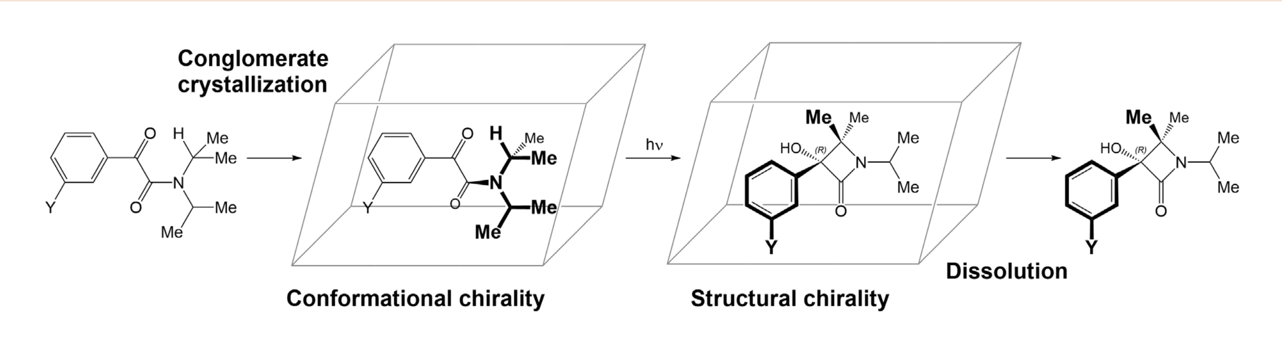


Figure 2. Absolute asymmetric synthesis with amplification mechanism through crystallization. The initial molecule at the left side is achiral whereas the final product at the right side exists as one or the other enantiomer. Y = H, F, Cl, Br, or I.

# Chemistry of Organic Materials group - ULB

## Research Summary

### Particle's helicity versus molecular chirality

In particle physics, helicity is the projection of a particle's spin onto the direction of its momentum. It measures the orientation of the spin relative to the motion, taking discrete values of "left-handed" (negative, spin antiparallel to the momentum) or "right-handed" (positive, spin parallel). For example, clockwise circularly polarized light consists of photons with a spin value of 1 aligned with the direction of propagation. A spin value of -1 corresponds to counterclockwise circularly polarized light. Based on the principle that only a chiral object recognizes a chiral object—the term "object" being taken in a very broad sense—chiral molecules interact differently with circularly polarized light. However, this observation can be extended to all particles with non-zero spin. Electrons with spin 1/2 also possess positive or negative helicity. In collaboration with the laboratory of Prof. Steven De Feyter at KU Leuven, we have shown that a single-atom chiral layer is sufficient to exhibit a magnetoconductance which varies according to the chirality of the molecules and the helicity of the electrons.[2] The current (I) - voltage (V) curves are illustrated in Figure 3. This result is significant because it contributes to a better understanding of why and how electron spin might control chemical reactivity. In this context, we are developing a library of chiral molecules designed to transport electric charges and induce spin polarization of electrons.

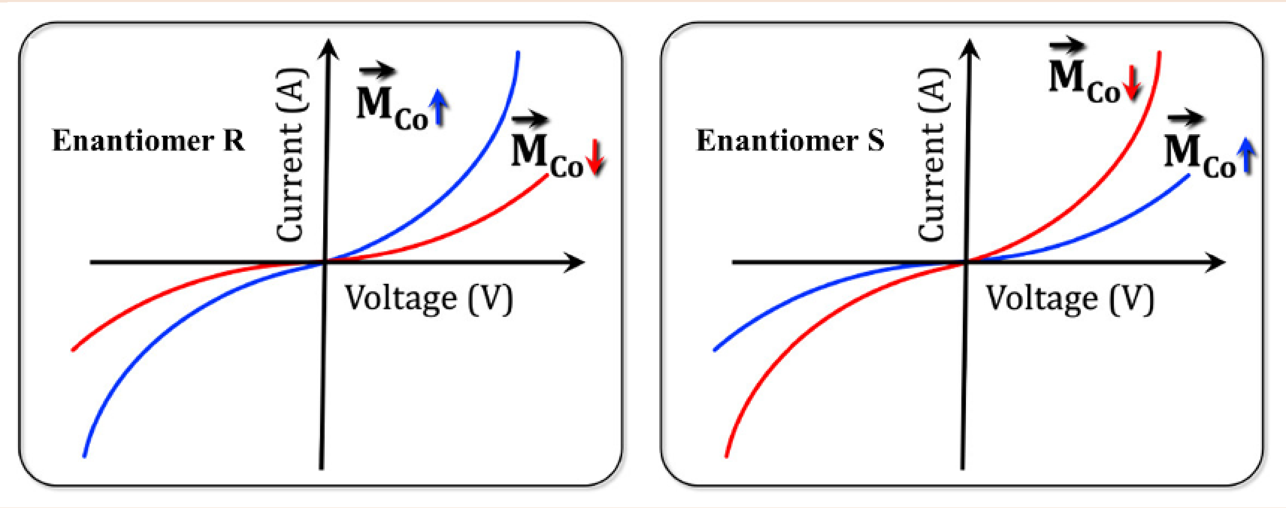


Figure 3. Schematic representation of current-voltage curves as a function of electron spin polarization (up ↑ or down ↓) and the chirality of molecules forming a monolayer on the surface of a gold electrode.

### Miscellaneous

In addition to the topics discussed above, we are continuing our research on the dimensionality of organic semiconductors and electronic devices,[1,2,3] but also on the engineering of crystal structures to tailor optoelectronic properties.[1,2] We recently published a mini review article dealing about the impact of molecular vibrations on transport properties in these materials.[1]

### CISSE Marie Skłodowska-Curie Doctoral Network

The research conducted in my group is multidisciplinary and naturally fits within the framework of European projects. I currently coordinate a Marie Skłodowska-Curie network that provides research training for ten doctoral students spread across six universities and two companies. The CISSE project is making a major contribution to understanding the chiral-induced spin selectivity (CISS) effect by bringing together some of the best European, Israeli, and American experts in the field.[7] To this end, the members of the CISSE consortium were selected for their expertise and complementary skills, particularly in synthetic chemistry, electrochemistry, surface science, biophysical chemistry, quantum chemistry, nanoscience, industrial processes, analytical chemistry, and the development of scientific instruments. The doctoral students were recruited internationally through a competitive process.

**Yves Geerts**

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## Chemistry of Organic Materials group - ULB

### Research Summary

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# Engineering of Molecular Nano-Systems laboratory - ULB

## Group of Gilles Bruylants, Kristin Bartik, and Hennie Valkenier

### Research Summary

The Engineering of Molecular NanoSystems (EMNS) laboratory1 is part of the Ecole polytechnique de Bruxelles (EPB) and is active in various research topics with applications mainly in the field of Health and Environment. The EMNS members have extensive know-how in the experimental study of the structure, stability and dynamics of supra- and macro-molecular systems, using advanced spectroscopic techniques and physico-chemical characterisation methods. The research of the laboratory is focusing on three main axes:

(i) Ion transport across lipid membranes using supramolecular carriers (Dr Hennie Valkenier).

(ii) Functionalised nanoparticles for (bio)sensors or smart contrast agents and delivery vectors (Prof. G. Bruylants),

(iii) The physico-chemical characterisation of supramolecular host systems (Prof. K. Bartik).

## Hennie Valkenier

**Dr. Hennie Valkenier** is a FNRS Research Associate and WEL Research Institute investigator and her research focusses on the transmembrane transport of ions across membranes using synthetic molecules. Lipid bilayer membranes define the borders of cells and their compartments. They act as impermeable barriers to ions and hydrophilic species, which can only cross the membrane with the help of specialised membrane proteins. She is developing molecules that can mimic these functions. Such 'ionophores' can insert into lipid bilayers, extract ions from the aqueous phase into the membrane, and move across to release them on the other side (Figure X).

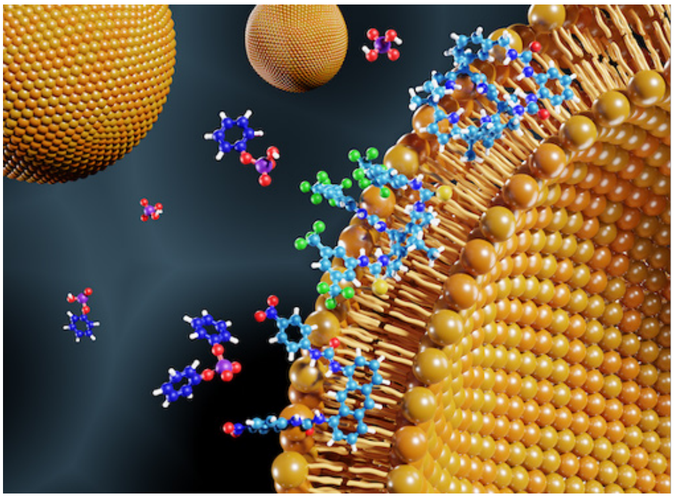

Figure X. Supramolecular anion receptors that are inserted in the lipid bilayer membrane of liposomes can transport anions into these liposomes.

In recent years, and with main funding from the FRNS and an ERC starting grant, she has developed ionophores for little explored ions of biological interest,[1] such as bicarbonate and phosphate anions[2] and copper(I) cations.[3] The development of ionophores involves the design and organic synthesis of the compounds, followed by the study of their ion binding and transport. Liposomes serve as model systems, often with emissive ion responsive probes encapsulated, so that the transport process can be monitored by fluorescence spectroscopy.[4]

Ionophores could find applications in the biological field, such as the treatment of channelopathies, which are genetic diseases linked to deficient transport by proteins, or for anti-cancer treatment. Our recently reported Cu(I) ionophores have been found to be very efficient in disrupting copper homeostasis and killing cancer cells.[3] Alternatively, the ionophores can be used as tools to control the entry of ions into cells or lipid-based nanoreactors,[5] or for sensing applications.

## Engineering of Molecular Nano-Systems laboratory - ULB

### Gilles Bruylants

**Prof. Gilles Bruylants** leads a research group focused on functionalizing nanomaterials for molecular sensing and smart drug-delivery applications. In collaboration with Prof. I. Jabin (ULB), he developed and patented an innovative nanomaterial-functionalization strategy that offers exceptional particle stability and precise control over surface coatings,[6] enabling advanced biomedical and environmental uses. This approach has successfully stabilized silver and silver–gold alloy nanoparticles, which exhibit superior plasmonic properties compared to gold nanoparticles.[7]

A recent FNRS-FRQ collaboration with Prof. M. Meunier (Polytechnique Montréal) applies these plasmonic nanoparticles, functionalized with calixarenes and antibodies, to improve lung-cancer diagnostics. Under lateral illumination microscopy, the nanoparticles appear as bright, countable dots, enabling objective quantification and multiplexed labeling using particles of different colors.[8] Their visualization with standard microscopes through an inexpensive, portable adapter supports clinical translation and personalized treatment selection.

With Innoviris funding, Prof. Bruylants and Dr. M. Retout. are also developing enzyme-responsive contrast agents for photoacoustic imaging and therapeutic delivery. This project aims to create a modular nanoplatform for cancer diagnosis and therapy using NIR-II photoacoustic imaging, photothermal therapy, and controlled release of anticancer peptides. Gold nanorods and silver nanotriangles absorbing in the NIR-II window will be functionalized with targeting and therapeutic peptides, serving as both imaging contrast agents and thermal transducers.

## Kristin Bartik

**Prof. Kristin Bartik** is Full Professor in the EMNS laboratory. Her research focuses on the fundamental factors that control molecular recognition in solution, with a focus on designing receptors capable of binding neutral or charged guests with high affinity and selectivity. Because most biological and environmental processes occur in water, a highly competitive solvent that effectively screens polar interactions and solvates binding partners, the challenge of achieving efficient recognition in aqueous media is pursued by encapsulating molecular receptors within micelles.[2,3] This strategy renders the systems water-compatible without requiring complex synthetic modifications, provides a protective microenvironment, and leverages the hydrophobic effect to enhance binding. To elucidate the mechanisms governing these recognition processes, extensive physicochemical characterization is conducted using UV-Vis absorption and emission spectroscopy, microcalorimetry, and advanced NMR methodologies.[2]

More recently, she has expanded her expertise to study how organic molecules—particularly lipids—interact with mineral matrices in archaeological ceramics and historical oil paintings. Using FTIR, NMR, GC-MS and Atomic Force Microscopy-Infrared Spectroscopy (AFM-IR), the aim is to develop innovative methodologies that can improve our capacity to detect, analyze, and interpret ancient materials, as well as enhance our understanding of their conservation.

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# Institute of astronomy and astrophysics - ULB

## Group of Nicolas Chamel, Stéphane Goriely, Alain Jorissen, Thibault Merle, Wouter Ryssens, Lionel Siess and Sophie Van Eck

### Research Summary

**New standards in binary- and multiple-star research**
T. Merle, A. Jorissen

Binary star research is important for astrophysics in several respects, but mainly because, by providing direct access to stellar masses through Kepler's third law, it allows to derive key calibrations like the mass – luminosity (M-L) relationship. This M-L relationship must rely on accurate 3D orbits (i.e., defining the full motion in space) which are not yet very numerous, because they require the availability and combination of different data (like spectroscopic measurements to derive the radial motion and astrometric measurements to characterise the on-sky motion). Only then can stellar masses be derived. This has been possible so far for only a few tens of binary systems.

It is therefore important to collect benchmark two-body stellar orbits, especially in anticipation of the massive release of orbits (on the order of 2 million) expected at the end of 2026 from the ESA Gaia satellite Fourth Data Release (Gaia DR4). Such benchmark orbits may be used to assess the quality of the Gaia DR4 orbits.

The Ninth Catalogue of Spectroscopic Binary Orbits (SB9, Pourbaix et al. 2004) is an historical compilation of spectroscopic binaries (SB) with orbital parameters. It is the online continuation of the SB8 catalogue (Batten et al. 1989) which contains 1469 SB systems and critical notes on most of the systems. Earlier versions of this catalogue, historically started at Lick Observatory with the five first versions of the SB catalogue (Campbell & Curtis 1905; Campbell 1910; Moore 1924, 1936; Moore & Neubauer 1948); then the effort was pursued at the Dominion Astrophysical Observatory with the sixth (Batten 1967), seventh (Batten et al. 1978) and eighth (Batten et al. 1989) versions of the catalogue. Since 2000, the catalogue was sponsored by the International Astronomical Union and hosted electronically at the Université Libre de Bruxelles. The last update of the SB9 catalogue by D. Pourbaix before passing away in November 2021 was done in March 2021. At that time, the SB9 catalogue contained more than 5 000 orbits. The queryable database is available at https://sb9.astro.ulb.ac.be.

## The SB9 catalogue

The SB9 catalogue serves as a reference and comparison sample for numerous studies on stellar binaries. For instance, it has been of fundamental importance for reviews on stellar multiplicity (e.g., Duchêne & Kraus 2013; Moe & Di Stefano 2017). The SB9 catalogue has been used to search for companions to close spectroscopic binaries (Tokovinin et al. 2006), for investigating solar-like oscillators (Beck et al. 2024) or solar twins (Simon & Obbie 2009), and for studying stellar rotation in B-type stars (Huang et al. 2010). It is also important for understanding the impact of the companions on the evolution of stars (e.g., Mazeh 2008; Eggleton & Tokovinin 2008), for searching for brown-dwarf companions (Sahlmann et al. 2011) or compact companions (Jayasinghe et al. 2023), and even in exoplanetary science (Winn & Fabrycky 2015).

## Evolution of SB9 towards a new version: SB$X$

The modernisation and extension of the SB9 catalogue has recently taken a decisive step forward. Building on the limitations identified in the legacy SB9 infrastructure (namely, flat file storage, inconsistent data formatting, limited search capabilities, and inflexible user interfaces), our work has led to the creation of the SB$X$ (The eXtended Catalogue of Spectroscopic Binary Orbits[1]), a scalable, standard-compliant platform designed to support the next decades of research on binary stars. At the core of this transformation is the migration of the entire catalogue to a modern PostgreSQL relational database. This new version enables more reliable and complex queries, eliminates duplicates, and establishes a solid foundation for future extensions.

## The Fourth Data Release from the ESA Gaia mission

The Gaia mission is an ambitious ESA spacecraft measuring the positions, parallaxes, proper motions and magnitudes of about 2 billion stars. In addition, the on-board Radial Velocity Spectrometer (RVS, Katz et al. 2023) provides radial velocities for more than 33 million stars. The third Data Release (DR3, Gaia Collaboration 2023a) includes the Non-Single Star catalogue (NSS, Gaia Collaboration 2023b) which outclasses, in a single release, all the binary catalogues known so far. In summary, the NSS catalogue includes 813 000 sources, and among them about 277 000 SB. The forthcoming DR4 NSS catalogue is expected to contain a few million orbits, and will set binary- and multiple-star research on new standards to which the ULB team is ready to participate.[2]

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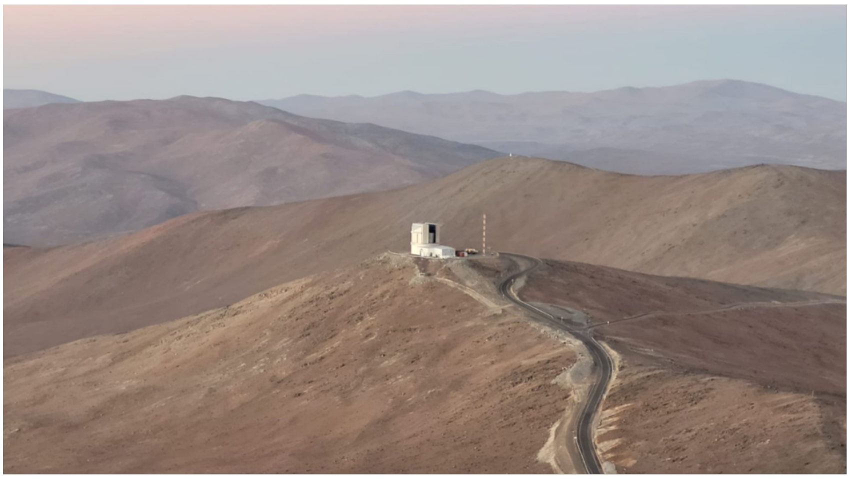
# Institute of astronomy and astrophysics - ULB

## The 4MOST Spectroscopic Survey

T. Merle

The 4-metre Multi-Object Spectrograph Telescope (4MOST) represents a technological pinnacle in astrophysical spectroscopy, located at the ESO's VISTA telescope in the Atacama Desert. As one of the world's largest stellar multi-object spectrographs, it utilizes fiber optics to simultaneously capture spectra for 2400 targets across high- and low-resolution modes. This facility provides critical data beyond simple imaging, including line-of-sight radial velocities, stellar properties and detailed chemical abundances. Since 2021, T. Merle has contributed to this 800-members consortium, focusing on the preparation of its five-year survey of the southern sky to map the Milky Way's history and large-scale cosmic structures. During the March 2026 science verification phase, T. Merle participated in on-site operations at 2800 m altitude at Cerro Paranal, managing real-time observational programming and technical challenges. This firsthand experience was vital for validating the data quality that will benefit the broader astronomical community. 4MOST now sets a new standard for high-multiplex spectroscopy, bridging complex systems engineering with fundamental galactic and extra-galactic research.



## Progress on the Study of Neutron-Capture Processes in CEMP-rs Stars: Heavy Element Abundances and Actinide Signatures

Riyas A.M., Karinkuzhi D., Van Eck S., Choplin A., Goriely S., Siess L.

### Observational Constraints from Heavy Neutron-Capture Elements

We investigate the origin of neutron-capture elements in carbon-enhanced metal-poor (CEMP) stars, with a particular focus on the poorly understood CEMP-rs subclass. In our first study (Riyas A.M., Karinkuzhi D., Van Eck S., Choplin A., Goriely S., Siess L., et al., 2026, ApJ, 997, 44), we derived detailed abundance patterns for a sample of CEMP-s and CEMP-rs stars using high-resolution ESO (European Southern Observatory) UVES spectra taken on the 8.2m telescope Kueyen. A key aspect of this analysis was the determination of abundances for a large number of heavy neutron-capture elements, including rarely measured species such as Tb, Ho, Tm, Yb, Lu, Ta, and Ir, whose spectral lines lie in the near-UV. These elements provide strong diagnostics to disentangle the contributions of the s-, r-, and intermediate (i-) processes. Using both classical indicators such as [Ba/Eu] and more robust model-independent metrics, we refined the classification of our sample, confirming the presence of both CEMP-s and CEMP-rs stars, and highlighting the difficulty of classification based solely on limited elemental information.

### The i-Process as an explanation for the CEMP-rs Abundance Patterns

We showed that the abundance patterns observed in CEMP-rs stars are well reproduced by i-process nucleosynthesis operating in low-mass, low-metallicity asymptotic giant branch (AGB) stars, likely triggered by proton-ingestion episodes. This result is consistent with earlier theoretical studies (e.g. Cowan & Rose 1977; Hampel et al. 2016, 2019; Denissenkov et al. 2017) and provides strong support for a single-site scenario for the origin of the peculiar hybrid abundance patterns observed in these stars. In particular, the inclusion of heavy r-process elements beyond the classical Eu–Dy range proves essential to constrain nucleosynthesis models and to distinguish between competing scenarios involving either the i-process or a combination of independent s- and r-process contributions (e.g. Jonsell et al. 2006; Bisterzo et al. 2012; Abate et al. 2016).

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## Detection of Actinides in CEMP-rs Stars

In a second study (Riyas A.M., Karinkuzhi D., Van Eck S., Choplin A., Goriely S., Siess L., et al., 2026, submitted to ApJ), we extend this analysis to the heaviest elements by investigating the presence of actinides in CEMP-rs stars. Using high-resolution ESO-UVES spectra and improved spectral synthesis including NLTE effects, we detected thorium in three stars and derived upper limits for uranium. The measured thorium abundances ([Th/Fe] ≈ 1.3–1.6) are comparable to those found in classical r-process-enhanced stars (e.g., Cowan et al. 2002; Hill et al. 2002; Frebel et al. 2007; Roederer et al. 2009), indicating that the nucleosynthesis processes responsible for the enrichment of CEMP-rs stars are capable of producing actinides at significant levels. This represents an important step toward linking the i-process with the production of the heaviest elements in the Universe.

## Implications for Nucleosynthesis and Galactic Chemical Evolution

Overall, our results provide strong evidence that the i-process occurring in low-mass AGB stars can account for the full range of neutron-capture elements observed in CEMP-rs stars, from the light s-process elements up to heavy r-process species and possibly actinides. Comparisons with AGB nucleosynthesis models computed with tools such as STAREVOL (Siess et al. 2000; Choplin et al. 2021, 2022) further demonstrate that i-process models provide a significantly better fit to the observed abundance distributions than pure s-process models. The detection of thorium also opens promising perspectives for cosmochronometry, offering a potential way to constrain the timescales of proton-ingestion events and the evolutionary history of these binary systems. While uncertainties remain, particularly regarding uranium detections and the possible contribution of mixed r+s scenarios, these studies significantly strengthen the case for the i-process as a major contributor to neutron-capture nucleosynthesis in the early Galaxy.

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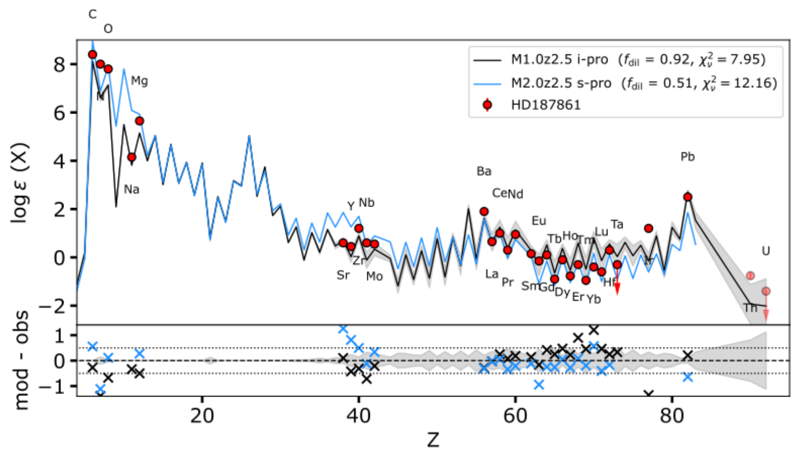


The abundance pattern of a CEMP-rs star is compared with nucleosynthesis predictions from the STAREVOL code. The measured abundances are indicated by red circles. Upper limits are indicated with downward arrows. In all cases, the best-fitting theoretical predictions for both the i-process (black) and s-process (blue) are displayed. The grey shaded area corresponds to the typical i-process nuclear parameter uncertainties.

# General Chemistry Research Group (ALGC) – VUB


## Group of Professors Frank De Proft, Frederik Tielens, Mercedes Alonso, Ionut Tranca and Professor Emeritus Paul Geerlings


### Research Summary

The research activities of the General Chemistry (Algemene Chemie, ALGC) focus on the fundamental and applied aspects of quantum chemistry. The group consists of two research subgroups performing complementary and synergistic research, i.e. the Chemical Theory group (F. De Proft and M. Alonso) and the Materials Modeling group (F. Tielens, I. Tranca). The Chemical Theory Group develops and implements chemical concepts and theories for challenging applications, involving the exploration of chemical reactivity in complex environments and molecular properties as well as the rational design of molecular compounds. The Materials Modeling Group investigates the physicochemical properties of solids and solid/liquid interfaces using state-of-the-art computational chemistry tools, including DFT and classical methods.

In both subgroups, fundamental aspects as well as applications are treated, the latter often in direct collaboration with experimental groups. A broad variety of substrates, ranging from atoms, small and medium-size molecules, polymers to solids and materials are thereby treated.

In this report, we summarize a few recent studies in the groups illustrating the broad and diverse research activities of ALGC in both fundamental and applied quantum chemistry.

### The Chemical Theory Group: 5 new PhDs

In this section, we highlight the work of 5 PhD students of the group that successfully defended their PhD theses recently.
Eline Desmedt's PhD thesis[1] addressed the rational design of functional molecular materials for optoelectronic applications. It focused on expanded porphyrins, and in particular hexaphyrin-based molecular switches, as promising candidates for near-infrared dyes and nonlinear optical (NLO) switching devices. Because the chemical compound space of these macrocycles is vast, the thesis moved beyond traditional trial-and-error molecular design and instead combined quantum-chemical calculations with inverse molecular design strategies to explore much larger regions of chemical space in a targeted way. The objective was to identify new switches with improved absorbance in the near-infrared region, enhanced first hyperpolarizability, and larger NLO contrast between their ON and OFF states.

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The thesis first established how aromaticity, topology, redox state, and structural distortion determine the spectroscopic and nonlinear optical behaviour of unfunctionalized hexaphyrins. Building on these structure–property relationships, inverse design procedures based on the best-first search algorithm were then used to optimize meso-substituted and core-modified hexaphyrins as high-contrast NLO switches. This led to extensive datasets that allowed the derivation of clear design rules, including distinct functionalization strategies for different redox switches and the identification of promising multistate switching motifs. To understand these trends at a deeper level, Eline further developed explainable machine-learning models using orbital, electronic, and charge-transfer descriptors, which clarified why different classes of hexaphyrins display markedly different optical responses. Altogether, this thesis demonstrates how quantum chemistry, inverse molecular design, and interpretable machine learning can be combined to accelerate the discovery of advanced molecular switches and to establish robust design principles for future functional optical materials.

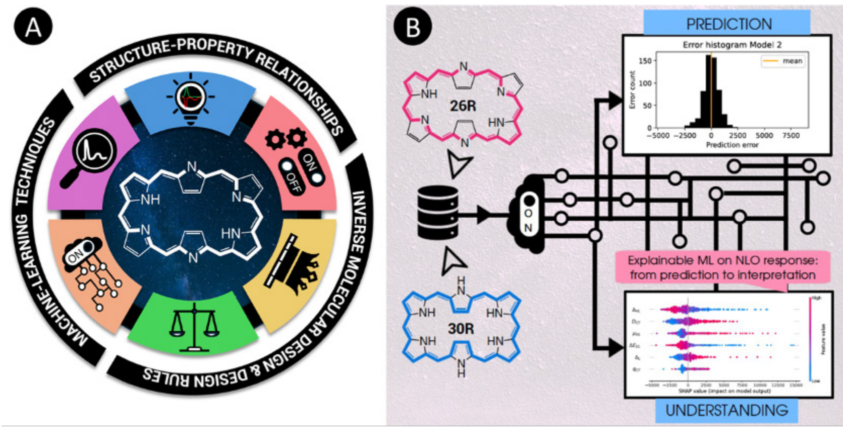


Figure 1. Summary of the research conducted during Eline Desmedt's PhD thesis. (A) Hexaphyrin-based molecular switches were investigated to unravel the structure–property relationships linking aromaticity, topology, redox state, and functionalization to optical response. (B) The integration of quantum chemistry, inverse molecular design, and explainable machine learning enabled the rational design of efficient near-infrared dyes and high-performance nonlinear optical switches. Reproduced from [2] and [3].

Nil Roig Vidal's PhD thesis,[4] a joint PhD between the VUB and the University of Warwick, highlights how the close integration of computation and experiment can deliver deep insight into organometallic structure, bonding, and reactivity. The work combined static DFT calculations with ab initio molecular dynamics and fragment-based energy decomposition analysis to study late transition metal pincer complexes, with particular emphasis on chemical bonding, electrostatic effects, and small-molecule activation. These methodologies were used to uncover mechanistic details of reversible C–C bond activation in mechanically interlocked systems, to rationalize spectroscopic behavior in metal carbonyl complexes, and to clarify the bonding and geometric preferences of nitrosyl complexes. Beyond explaining experimental observations, the computational results also guided new synthetic developments, illustrating the thesis' strongly synergistic theory–experiment approach.

Importantly, the methodologies developed in this thesis have already proven powerful beyond the original systems under study. They enabled the identification of a new type of s-block metal–lanthanide bonding through the comparison of Mg–Yb and Mg–Ca complexes,[5] and they also underpinned the synthesis and characterization of a landmark Mg(0) complex featuring a polarized $Mg^{\delta-}$–$Ca^{\delta+}$ bond. Nil's PhD work therefore not only deepened our understanding of late transition metal pincer chemistry, but also delivered a powerful computational toolkit for uncovering unprecedented bonding motifs in main-group and f-element chemistry.

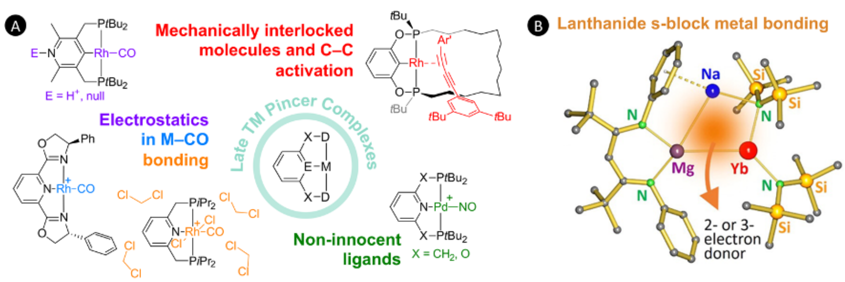


Figure 2. (A) Summary of the research conducted during Nil Roig Vidal's PhD thesis. Late transition metal pincer complexes were used as a platform to demonstrate the power of combining experimental and computational approaches to unravel the bonding, properties, and reactivity of organometallic systems. (B) The computational methodologies developed in this work were further extended to uncover unprecedented lanthanide–s-block metal bonding. Insert B reproduced from [6].

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Bin Wang's PhD thesis[7] focused on the analytical development of so-called Conceptual Density Functional Theory (CDFT) response functions, providing a clear and detailed derivation and implementation of these quantities up to second order. CDFT, derived from Density Functional Theory (DFT), provides a robust framework for understanding chemical reactivity. Through the introduction of these response functions, derivatives the energy of the system with respect to the number of electrons and/or the external potential (i.e. the potential due to the nuclei), CDFT rigorously defines several well-known but previously vaguely defined concepts, such as the electronic chemical potential (electronegativity), hardness, softness, and others.

Numerical differences between widely used approximations of these response functions (e.g. using frontier molecular orbitals or the finite difference approximation) and the analytical results obtained through the Coupled-Perturbed Kohn-Sham scheme were carefully examined in this thesis. Besides improving the prediction of the chemical selectivity using traditional CDFT, the analytical evaluation, more specifically in the case of the chemical hardness, also opens the room for investigating the fundamental failures of DFT e.g. the delocalization error of modern density functional approximations. In a subsequent step, an extension from the atoms-in-molecules resolution to chemical bond resolution through the newly introduced conceptual density matrix functional theory (CDMFT) was presented. CDMFT offers a new perspective for exploring bond reactivity, including the description of bond–bond polarizability. An important application of CDMFT was demonstrated through the simulation of primary bond cleavage in electron impact mass spectrometry using response properties. In a final part of the thesis, through the combination of CDFT and concepts from the information-theoretic approach in DFT, a new reactivity partitioning method of the reaction coordinate of an elementary reaction step was proposed to divide the full reaction path into segments that are individually controlled by physically meaningful factors such as electrophilicity/nucleophilicity and steric effects.

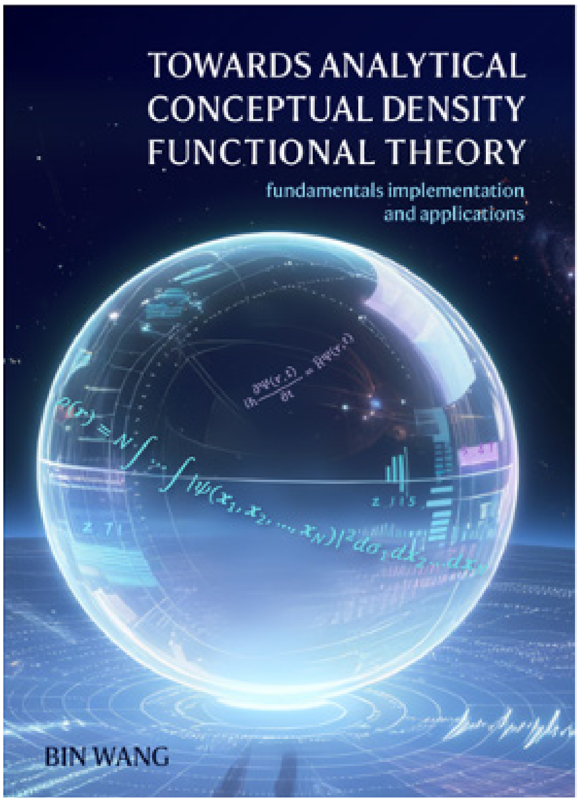


Figure 3. Cover of the PhD thesis of Bin Wang.

The PhD thesis of Charlotte Titeca[8] aimed at obtaining increased insight into molecular processes involving compounds containing unbound electrons, so-called electronic resonances. This thesis was a joint PhD between KULeuven as the main institution and the VUB as partner institution. In her work, Charlotte paid particular attention to dissociative electron attachment, taking place when electron attachment to a stable molecule results in formation of an electronic resonance undergoing bond breaking. This process is omnipresent and occurs for instance in DNA after exposure to radiation and is as such exploited for treating cancer using radiotherapy.
The presence of an unbound electron requires the use of adapted techniques. In the thesis, two different approaches were applied: charge stabilization and addition of a complex absorbing potential. In the former method, the molecule is artificially modified such that the unbound electron becomes bound and can be treated using the conventional quantum chemical methods. An extension of the original charge stabilization method beyond the calculation of energies was put forward and applied to obtain the electron localization function that shows were the unbound electron is localized. This allowed the the development of an approach for predicting whether dissociative

electron attachment will occur and which bond(s) will be most affected.
Next, molecules with a cage-like structure that are hypothesized to catch an electron inside the cage were scrutinized. The bound or unbound character of the excess electron was found to depend on the specific method used for describing these molecules. The extension to charge stabilization was applied to investigate whether the electron is really located in the cage and how its description varies among different methods.
In the final part, the complex absorbing potential was considered. It acts like a wall preventing the unbound electron from leaving the system. Combinations of this approach with density-based methods are very scarce in scientific literature and software. An implementation of complex absorbing potentials for density functional theory was performed and the first results obtained using this promising method were reported.

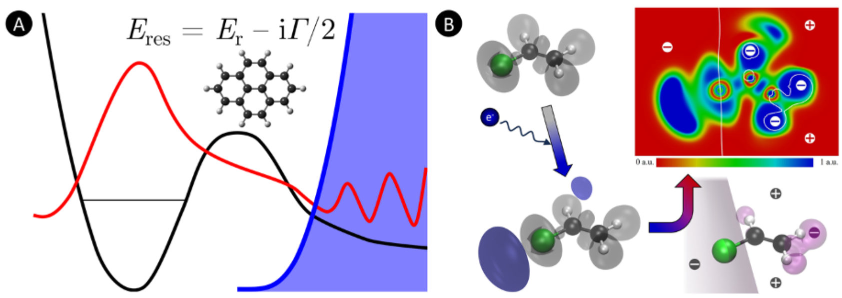


Figure 4. Representative graphical abstracts from the PhD of Charlotte Titeca. (A) Extension of a complex absorbing potential approach to DFT (B) Combination of the charge stabilization methods with the electron localization function to investigate bonding in metastable anions. Reproduced from [9] and [10]

Jochen Eeckhoudt's PhD thesis[11] focused on high pressure chemistry. This is interdisciplinary subfield of chemistry and physics with a long and rich history spanning over a century. It has provided numerous advancements in the fields of chemical synthesis, superconductivity, superhard materials and other exotic chemical compounds. In recent years, new models that allow for a quantum mechanical description of molecules under pressure have been developed and these models were used in Jochen's work to study several aspects of high-pressure chemistry. First, chemical concepts such as electronegativity and chemical hardness were studied at high pressure by extending the conceptual density functional framework. These were shown to already explain several observations encountered in the high-pressure world. Next, several models to impose pressure on molecules meticulously compared against each other. The results stressed the importance of a proper description of the boundary between the molecule and the pressurizing medium. A more theoretical section then attempted to derive an equation for and subsequently compute the change of the dipole moment of molecules when the pressure increases. As a step towards larger molecules, the aromaticity concept was investigated under pressure for benzene, leading to several recommendations to the community. Finally, the ring opening reaction of Dewar benzene was studied, and it was shown that reaction properties accessible through high pressure experiments can be matched to theory to better understand the underlying mechanism. As an epilogue, cation-ϖ interactions between the side chains of amino acids in proteins were studied using a combined statistical and theoretical approach. This revealed that the perceived prevalence and importance of these interactions might be overstated.


Figure 5. (A) Cover of the PhD tesis of Jochen Eeckhoudt and (B) summary figure of the research topics in the thesis.

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## The Materials modeling Group: Computational Perspectives on Catalysis and Adsorption: From Electrochemical Interfaces to Amorphous Silica and Metal Nanoclusters

The studies carried out by the materials modeling group that will be highlighted in this section convincingly demonstrate that catalytic and adsorption phenomena are governed by a subtle interplay between electronic structure, surface heterogeneity, and environmental effects. From electrochemical interfaces to amorphous oxides and nanoclusters, reactivity cannot be attributed to a single factor but emerges from the coupling of multiple scales and interactions. Computational chemistry is shown to provide a powerful framework to capture this complexity and to guide the rational design of advanced catalytic systems across disciplines.

### *1. Electrolyte-controlled co$_2$ reduction kinetics[12]*

Electrochemical $CO_2$ reduction represents a promising pathway to convert carbon dioxide into value-added chemicals under mild conditions. Beyond catalyst design, the electrolyte exerts a decisive influence on activity and selectivity by shaping the interfacial environment at the electrode–electrolyte boundary. Variations in pH alter proton availability and the thermodynamic driving force of proton-coupled electron transfer steps, while alkali cations accumulate within the electric double layer and stabilize key intermediates through electrostatic and non-covalent interactions. Larger cations, for instance, are known to promote C–C coupling on copper surfaces, thereby enhancing the formation of multi-carbon products. At the same time, anions and buffer species influence local pH gradients and mass transport, dynamically modifying the reaction environment during operation. These coupled effects demonstrate that catalytic performance in $CO_2$ cannot be understood without explicitly considering electrolyte composition and interfacial phenomena.

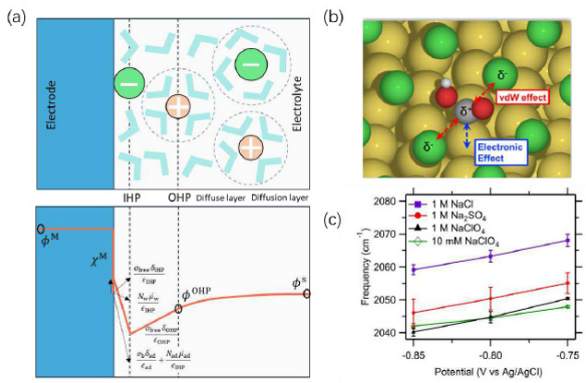


Figure 6. Representative reaction pathways for C1 and C2 products in CO2. Figure reproduced from [12].

### *2. Ru(III) single-site catalysts in amorphous silica*[13]

Amorphous silica-supported catalysts present a fundamentally different landscape compared to crystalline materials due to their intrinsic structural disorder. In the case of Ru(III) single-site catalysts embedded in MCM-41-type frameworks, the diversity of silanol groups and siloxane bridges generates a wide distribution of coordination environments. Periodic DFT modelling revealed that the incorporation and stability of Ru(III) centers depend strongly on both local geometry and the presence of surfactant molecules retained within the pores. These organic species stabilize charged intermediates and influence hydrogen-bonding networks, thereby favoring specific coordination motifs such as fully oxidic or partially hydroxylated Ru species. Importantly, some of the most stable configurations also facilitate hydride formation, linking structural stability directly to catalytic reactivity. This highlights that in disordered systems, catalytic behavior emerges from an ensemble of accessible sites rather than a single well-defined active center.

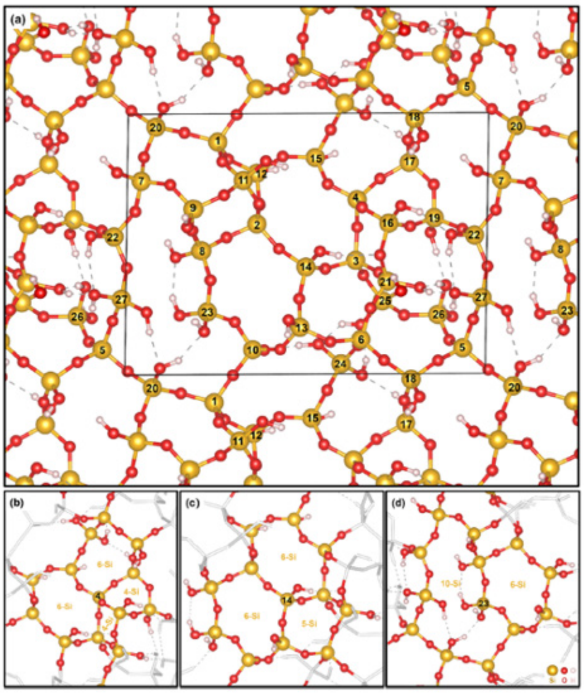


Figure 7. Schematic representation of Ru(III)@MCM-41 catalyst structure and site distribution. Figure reproduced from [13].

## General Chemistry Research Group (ALGC) – VUB

### *3. Adsorption of phosphorus-bearing molecules on amorphous silica*[14]

The interaction of phosphorus-bearing molecules with amorphous silica provides insight into both terrestrial and astrochemical surface processes. DFT calculations show that adsorption of species such as PO, $PO_2$, POH, HPO, and $PH_3$ is exothermic and dominated by chemisorption mechanisms involving silanol groups and bridging oxygen atoms. The heterogeneous nature of the silica surface leads to a variety of adsorption geometries, reflecting the diversity of available active sites. Beyond adsorption energetics, vibrational spectroscopy plays a crucial role in identifying these species, as each molecule exhibits characteristic infrared signatures upon adsorption. These spectroscopic fingerprints enable direct comparison with experimental observations, bridging the gap between computational predictions and measurable properties in complex environments such as interstellar dust or soil systems.

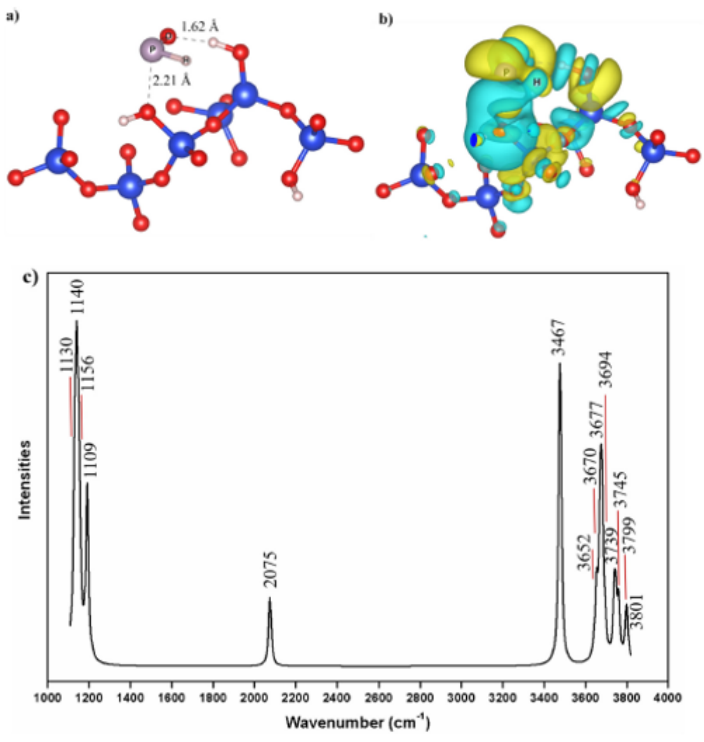


Figure 8. Adsorption configurations of HPO molecules on amorphous silica. Figure reproduced from [14].

*4. Ab initio dynamic approaches and experimental Raman of calcium carbonate polymorphs*[15]

A complementary perspective on structure–spectra relationships is provided by the recent study on calcium carbonate polymorphs, where advanced ab initio dynamic approaches are combined with experimental Raman spectroscopy. Moving beyond conventional static DFT methods, the work demonstrates that accurate vibrational spectra of ionic materials require explicit inclusion of anharmonicity, temperature effects, and configurational sampling through AIMD-based autocorrelation function techniques. A key methodological advance lies in the use of a fully ab initio Voronoi partitioning derived from Bader analysis, which significantly improves the description of electromagnetic properties. The approach successfully reproduces the Raman signatures of calcite, aragonite, and vaterite, and provides strong evidence that the $\nu_1$ band of vaterite is intrinsically a triplet. More broadly, this study establishes a robust and transferable framework for the predictive modelling of vibrational spectra in complex ionic and disordered materials.

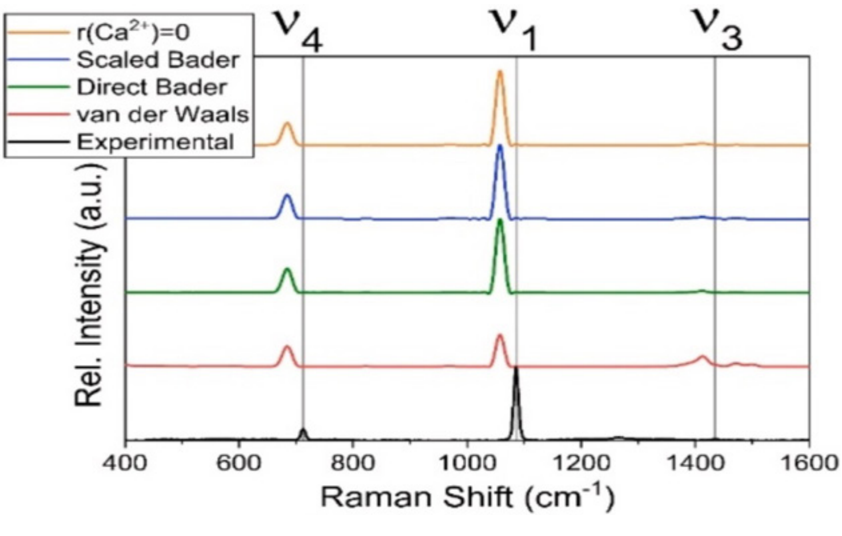


Figure 9. Dynamic unpolarized Raman spectra for calcite. Different spectra for different choices of Voronoi radius are reported as well as the experimental Raman spectrum. Figure reproduced from [15].

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*5. Design criteria for water splitting OER electrocatalysts*[16]

The ongoing climate crisis and dependence on fossil fuels are driving an urgent search for sustainable energy solutions, including the storage of excess energy in the form of chemical bonds such as hydrogen ($H_2$). Hydrogen is an attractive energy carrier due to its high energy density, its potential production from water using renewable electricity, and its carbon-free use. $H_2$ can be produced via electrochemical water splitting in proton exchange membrane water electrolyzers (PEMWEs). When coupled with renewable electricity sources, this approach represents a promising route toward green hydrogen production. However, several challenges still limit the widespread deployment of PEMWE technology. In particular, the oxygen evolution reaction (OER) remains a major bottleneck due to the reliance on expensive and scarce catalysts, primarily based on iridium and ruthenium. Advancing PEMWE systems therefore requires improving the performance and durability of these catalysts, while minimizing their loading, enhancing their utilization efficiency, and ultimately developing alternative materials that reduce or replace the need for these critical elements.

Multiple descriptors have been developed and refined to enable the rapid and reliable screening of promising catalytic materials. Most of these descriptors are based on the adsorption energies of key OER intermediates ($\Delta EHO^*/\Delta EO^*/\Delta EHOO^*$) formed at the active sites of a multitude of electrocatalysts. Linear scaling relationships between the adsorption energies of these intermediates (e.g., $\Delta EHOO^*=\Delta EHO^*+3.1\text{-}3.3$ eV or $\Delta EO^*=1.61\Delta EHO^*+1.43$ eV), were shown to limit the overpotential. The majority of the studies, debated the limiting potentials given by the scaling between HOO* and HO* moieties. On the other hand, the scaling relationship between O* and HO* exhibits a significant scatter of data along the scaling slope, that needs further investigations.We derived five distinct scaling relationships between $\Delta EO^*$ and $\Delta EHO^*$, obtained by partitioning the dataset into subsets based on predicted theoretical overpotential ranges.

This approach provides a better understanding of the optimal relationships between these adsorption energies, required in order to approach lower overpotentials.

According to these scaling relationships, the best materials should exhibit in the same time (see in Figure 10) the following requirements: *(i) adsorption energies of HO* within a narrow window (-0.5, 1.5 eV) (see the gray shadow in Figure 10); (ii) a scaling relation between the adsorption energies of O* and HO* of: ΔEO* = ΔEHO* + 1.81 eV with a MAE = 0.15 eV (see the trends given by the red points in the two plots of Figure 10); (iii) a scaling relation between the adsorption energies of HOO* and HO* with an intercept of 3.03 eV and an MAE=0.2 eV, which is lower than the intercept for all datasets (3.14 eV) (see the relation in smaller plot of Figure 10 – that summarizes the three requirements to be fulfilled).*

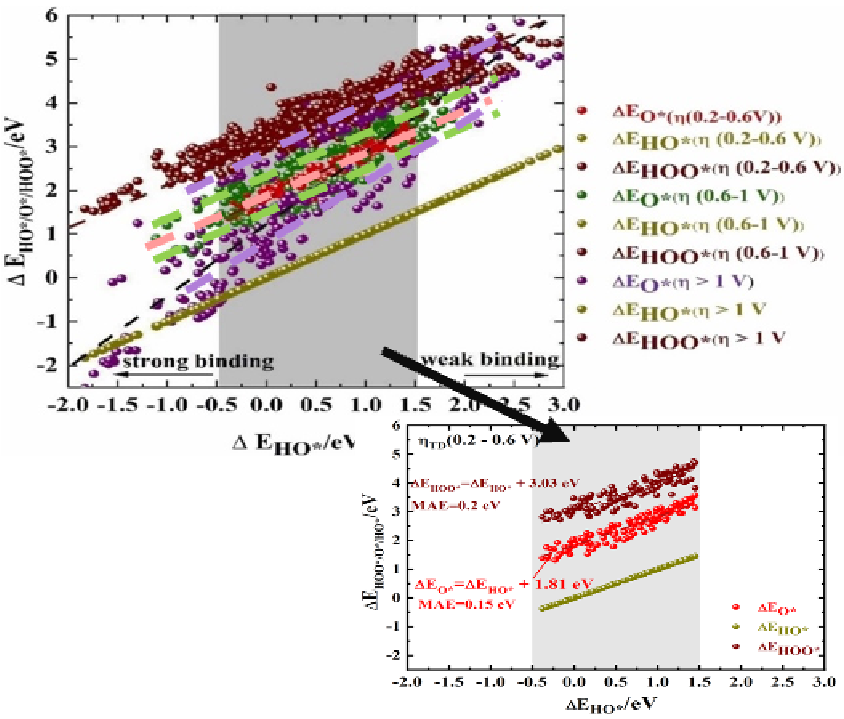


Figure 10. The research for trends of the adsorption energies of the OER intermediates: ΔEHO*/ ΔEO*/ ΔEHOO*. Red, green and purple points together with dashed lines represents the 5 scaling relations derived for ΔEO* vs. ΔEHO*. The red points correspond to the best materials (see separately in the graph). Reproduced from [16].

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[1] PhD thesis Eline Desmedt, "Exploring the chemical compound space of hexaphyrin-based nonlinear optical switches with inverse molecular design". Promotors: Prof. F. De Vleeschouwer (VUB) and Prof. M. Alonso (VUB).

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[4] PhD thesis Nil Roig Vidal, "Molecular dynamics simulations and energy decomposition analysis of late transition metal pincer complexes and supporting experimental work". Promotors: Prof. A. B. Chaplin (University of Warwick, UK) and Prof. M. Alonso (VUB).

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[7] PhD thesis Bin Wang, "Towards Analytical Conceptual Density Functional Theory: Fundamentals, Implementation and Applications". Promotors: Prof. F. De Proft and Prof. P. Geerlings (VUB); Co-promotor: Prof. S. Liu (University of North Carolina, Chapel Hill, USA).

[8] PhD thesis Charlotte Titeca, "Computational and Conceptual Density Functional Theory for Electronic Resonances". Promotors: Prof. T.-C. Jagau (KULeuven) and Prof. F. De Proft (VUB).

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# Topological Quantum Matter and Driven Quantum Many-Body Physics

## Group leader: Nathan Goldman

**Professor Nathan Goldman** has joined in 2025 the International Solvay Institutes as "Group leader". His broad research interests cover the exciting fields of quantum gases, quantum simulation, topological states of matter, quantum Hall physics, quantum geometry, periodically-driven quantum systems and topological photonics. A more detailed description of his current research follows. The International Solvay Institutes are honored and proud of this recruit, which formalizes the long-term precious help of Professor Goldman in the organization of many Solvay activities.

### Research Summary

The year 2025 saw major advances across topological phases of matter, Floquet engineering, impurity-based probes of quantum many-body systems, and the emergence of anyonic statistics in ultracold gases. These developments significantly deepened the understanding of non-equilibrium quantum dynamics, strongly correlated phenomena, and topological responses. Their visibility - through publications in Nature, Nature Communications, Physical Review Letters, Physical Review X - highlights the broad impact and leadership of this research program within the quantum science community.

#### 1. Topological Transport and Floquet Physics

- Thouless pumping in a driven-dissipative Kerr resonator array (Phys. Rev. Lett. 134, 093801 (2025)) demonstrated quantized adiabatic pumping in a nonlinear photonic lattice subject to drive and dissipation, showing the robustness of topological transport in realistic photonic platforms.

- The Středa Formula for Floquet Systems (Phys. Rev. X 15, 031067 (2025)) established a generalized Středa relation for periodically driven systems using Cesàro summation, providing new tools to characterize topological invariants and anomalies in Floquet matter. These contributions strengthened the theoretical foundations of topological transport in non-equilibrium systems.

**2. Impurity-Based Probes of Quantum Many-Body Phenomena**

- A central theme emerging this year is the use of impurities as precision probes of complex quantum environments.

- Chiral polaron formation on the edge of topological quantum matter (Nature Communications 16, 4918 (2025)) revealed how impurities can bind into chiral polarons at the edges of topological systems, offering a microscopic probe of edge-state structure.

- Quantum Impurities in Finite-Temperature Bose Gases (Phys. Rev. Lett. 135, 253401 (2025)) demonstrated that impurities can detect vortex proliferation across the BKT transition and the onset of Bose–Einstein condensation, establishing impurity dynamics as a sensitive diagnostic of finite-temperature phase transitions.

These works show that quantum impurities provide a unifying and versatile strategy for probing both topological and thermal many-body phenomena.

**3. Emergent Quasiparticles and Dynamically Engineered Topological Modes**

- Dynamic Realization of Majorana Zero Modes in a Particle-Conserving Ladder (Phys. Rev. Research 7, 023183 (2025), Editors' Suggestion) introduced a mechanism to dynamically generate Majorana zero modes without breaking particle-number conservation, opening new avenues for realizing topological superconductivity in cold-atom platforms.

- Circular Dichroism on the Edge of Quantum Hall Systems (Phys. Rev. Lett. 135, 266603 (2025)) connected circular dichroism measurements to many-body Chern numbers and anisotropy effects, proposing experimentally accessible probes of correlated topological phases.

### 4. Anyon Physics and Strongly Correlated Bosons

Two landmark publications advanced the realization and modeling of anyonic statistics in ultracold atomic systems.

- Anyonization of bosons (Nature 642, 53 (2025)) reported the experimental realization of tunable anyonic behavior in a bosonic gas, marking a milestone in the exploration of fractional statistics.

- Anyonization of bosons in one dimension: an effective swap model (Phys. Rev. Lett. 135, 253403 (2025)) provided the theoretical framework underpinning the experiment, introducing an effective model capturing the essential physics of one-dimensional anyonization.

These works represent a major step toward controllable anyonic matter and its potential applications in quantum simulation and topological quantum computation.

### Conclusion

The 2025 publications highlight a coherent and ambitious research program spanning:

- topological transport and Floquet engineering.

- impurity-based probes of many-body physics.

- emergent quasiparticles and edge phenomena.

- the groundbreaking realization of anyonic statistics in neutral atomic gases.

The visibility and impact of these results reflect the significant contributions made to the ongoing development of topological and strongly correlated quantum systems.

# Topological Quantum Matter and Driven Quantum Many-Body Physics

## Publications


[1] Anyonization of bosons,Sudipta Dhar, Botao Wang, Milena Horvath, Amit Vashisht, Yi Zeng, Mikhail B. Zvonarev, Nathan Goldman, Yanliang Guo, Manuele Landini and Hanns-Christoph Nägerl, Nature (2025)

[2] Chiral polaron formation on the edge of topological quantum matter,Amit Vashisht, Ivan Amelio, Laurens Vanderstraeten, Georg M. Bruun, Oriana K. Diessel and Nathan Goldman,
Nature Communications 16, 4918 (2025)

[3] Dynamic Realization of Majorana Zero Modes in a Particle-Conserving Ladder,
Anais Defossez, Laurens Vanderstraeten, Lucila Peralta Gavensky and Nathan Goldman,
Phys. Rev. Research 7, 023183 (2025); Editors' Suggestion

[4] Thouless pumping in a driven-dissipative Kerr resonator array, S. Ravets, N. Pernet, N. Mostaan, N. Goldman and J. Bloch, Phys. Rev. Lett. 134, 093801 (2025)

# The Robert Brout and Ilya Prigogine Prizes

In order to commemorate the memory of two exceptional scientists from the University of Brussels, the juries of the masters in chemistry and in physics of the ULB and the VUB have created:

- The Ilya Prigogine Prizes, to be awarded to the best students finishing their master studies in chemistry, provided they have a brilliant curriculum;

- The Robert Brout Prizes, to be awarded to the best students finishing their master studies in physics, provided they have a brilliant curriculum.

Given the close ties of these two personalities with the Institutes, the International Solvay Institutes are associated with this initiative.

## Laureates

In 2025, the prizes have been awarded to:

Stef Duponcheel: Prix Brout, VUB

Selma Youcef Khodja: Prix Brout, ULB

Lucille Van Nuffel: Prix Brout, ULB

Lucie De Jong Prix Prigogine, ULB

Phoenix Heylighen Prix Prigogine, VUB

# 06

# APPENDICES

## Press and newspapers

### La Dernière Heure - 08.10.2025

**Prix Nobel de chimie : " C'est une journée palpitante, excitante, indescriptible " pour Omar Yaghi**

Le professeur jordano-américain Omar M. Yaghi, lauréat du prix Nobel de Chimie mercredi aux cô tés du Japonais Susumu Kitagawa et de l'Australien Richard Robson, a décrit une journée " excitante, palpitante, indescriptible ". Il était présent à Bruxelles pour l'ouverture du 27e Congrès Solvay sur la chimie, qui se tient du 9 au 11 octobre à Bruxelles.

M. Yaghi et ses collègues ont été récompensés pour leurs travaux sur les matériaux réticulaires (MOFs). Ils ont ainsi créé des " éponges moléculaires ", des structures comportant de grands espaces à travers lesquels peuvent circuler des gaz et d'autres substances chimiques. Les deux grands thèmes de ces travaux sont la capture du $CO_2$ et la récolte des molécules d'eau contenues dans l'air.

" Nous avons atterri ce matin après un vol de 10 heures en provenance de San Francisco lorsque mon téléphone a sonné. D'habitude, je demande aux gens de communiquer avec moi par SMS. Mais là, j'ai vu que ça venait de Suède donc je me suis dit qu'il valait mieux décrocher ", a raconté le scientifique en conférence de presse d'introduction du Congrès Solvay.

M. Yaghi est en effet membre du Comité scientifique international des Instituts Solvay, au sein desquels il contribue à définir les orientations des programmes scientifiques. Il a aussi remporté le prix Solvay en 2024, tout comme son colauréat Susumu Kitagawa en 2017.

Il avait par ailleurs présenté le fruit de son travail à Flagey en 2022 lors de la conférence de vulgarisation qui suit traditionnellement le Congrès Solvay et dans laquelle des scientifiques de haut niveau viennent expliquer leur travail au grand public.

Dans le cadre de sa Chaire Solvay, Omar Yaghi a également donné cours à des chercheurs de l'ULB et de la VUB pendant deux mois.

## La Libre - 08.10.2025

### Omar Yaghi, tout juste couronné prix Nobel de chimie, est à Bruxelles : " Une nouvelle façon de penser la chimie au service du monde réel "

Prix Nobel de chimie 2025, le Jordano-Américain est à Bruxelles pour la conférence Solvay. Ses " architectures moléculaires " ouvrent la voie à une chimie capable de piéger le $CO_2$, purifier l'eau ou extraire l'humidité de l'air.

Omar Yaghi donne sa première conférence de presse en personne en tant que lauréat du prix Nobel de chimie 2025, à l'hôtel Le Plaza à Bruxelles. À ses côtés, Marc Henneaux, physicien théoricien belge et professeur à l'Université libre de Bruxelles, modère la rencontre. ©Valentin Hammoudi / La Libre

Il a reçu le coup de fil lui annonçant qu'il venait de remporter le prix Nobel de chimie 2025...dans un avion. " Nous venions d'atterrir après un vol de dix heures entre San Francisco et Francfort. J'étais prêt à me lever pour sortir de l'avion quand mon téléphone a sonné. Et quand j'ai vu que l'appel venait de Suède (le comité Nobel est basé là-bas, NDLR), je me suis dit que c'était un appel que je devais prendre ! (rire) ", a raconté Omar Yaghi, sourire discret et regard lumineux, ce mercredi à l'hôtel La Plaza, à Bruxelles.

Le chercheur, désormais professeur à l'Université de Californie à Berkeley, s'apprêtait à participer à la 27e Solvay Conference on Chemistry, qui réunit cette semaine les grands noms du domaine. C'est à cette occasion qu'il a donné dans la capitale belge sa première conférence de presse en personne en tant que lauréat du prix Nobel, qu'il partage avec le Japonais Susumu Kitagawa et le Britannique Richard Robson.

Omar Yaghi, tout juste couronné prix Nobel de chimie, est félicité à Bruxelles par Ben Feringa, un chimiste néerlandais lauréat du prix Nobel de chimie en 2016. ©Valentin Hammoudi / La Libre

### Une architecture moléculaire révolutionnaire

Le trio est récompensé pour le développement des metal–organic frameworks (MOF), des structures moléculaires < https://www.lalibre.be/planete/sciences-espace/2025/10/08/trois- scientifiques-recompenses-du-prix-nobel-de-chimie-2025-pour-leurs-eponges-moleculaires- capables-de-capturer-le-co2-et-stocker-lenergie-XD5WT4XEVJDOJGMI2FMH73AKGQ/ > capables de créer de véritables “ cages ” à gaz. “ Ces matériaux ont ouvert une mine d'or scientifique ”, explique Omar Yaghi. Constitués d'ions métalliques reliés par des molécules organiques, ils forment des cristaux poreux dont les cavités peuvent être conçues sur mesure pour capturer des substances spécifiques : dioxyde de carbone, eau, polluants, voire PFAS, ces produits chimiques persistants qui contaminent nos rivières. Certains MOF peuvent même servir de catalyseurs ou conduire l'électricité.

L'idée, née dans les années 1990, a profondément transformé la chimie des matériaux. “ La beauté de la chimie, c'est que si vous apprenez à contrôler la matière au niveau atomique et moléculaire, le potentiel devient immense ”, expliquait Omar Yaghi au comité Nobel.

### De la recherche au terrain : un potentiel colossal

À Bruxelles, Omar Yaghi a insisté sur les nombreuses applications concrètes déjà en cours. “ Ce n'est plus de la science-fiction : plusieurs start-ups aux États-Unis utilisent nos matériaux pour produire de l'eau à partir de l'air, notamment dans des environnements désertiques ”, souligne-t- il. Les mêmes principes pourraient bientôt permettre de capturer le dioxyde de carbone des usines ou de filtrer les polluants chimiques dans les eaux usées. “ Nous avons désormais les outils pour rendre la chimie plus propre et plus utile à la planète. C'est un changement de paradigme : la matière devient un allié face à la crise climatique”.

Et pour lui, l'intelligence artificielle pourrait bien amplifier cette invention : " Prendre l'IA < https://www.lalibre.be/planete/environnement/2025/10/08/lia-et-ladn-environnemental-pour- traquer-les-especes-invasives-en-europe-une-revolution- SV72E5YSBVAIXILPACFNHW3HBY/ > et la développer avec l'expérience, combiner ces deux dimensions pour simplifier au maximum les tâches que nous effectuons au laboratoire. Mes étudiants ont déjà accompli en deux semaines ce qu'il aurait fallu deux ans à faire, simplement en utilisant ChatGPT ", explique-t-il.

Les perspectives industrielles s'étendent bien au-delà du laboratoire. Des prototypes de systèmes portables de collecte d'eau atmosphérique fonctionnent déjà dans certains déserts, tandis que d'autres équipes testent des filtres à base de MOF pour piéger le CO dans les gaz d'échappement. " Ce prix Nobel reconnaît non seulement une découverte fondamentale, mais aussi une nouvelle façon de penser la chimie au service du monde réel ", conclut Omar Yaghi.

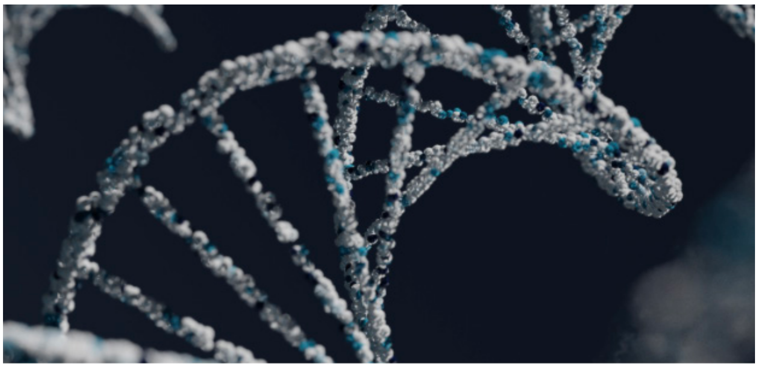
**De réfugié palestinien à figure mondiale de la science**

Mais au-delà de la découverte, le parcours d'Omar Yaghi incarne la force de la science comme ascenseur social. Né en 1965 en Jordanie, dans une famille modeste de réfugiés palestiniens, il a grandi sans électricité ni eau courante. Enfant, il se faufile un jour dans la bibliothèque de son école, découvre un livre de chimie et tombe sous le charme de ces mystérieuses structures dessinées dans les pages. À 15 ans, son père l'envoie étudier aux États-Unis. Quarante ans plus tard, il devient l'un des chimistes les plus cités au monde.

" Les gens talentueux existent partout. Nous devons libérer leur potentiel en leur offrant des opportunités ", aime-t-il rappeler. À Bruxelles, Omar Yaghi insiste aussi sur la responsabilité des scientifiques face aux grands défis planétaires : " Notre but n'est pas seulement de découvrir, mais d'inventer des solutions pour un monde plus durable. "

## ULB - 10.10.2025

### Omar Yaghi, prix Nobel 2025 au Conseil de Chimie Solvay



À peine proclamé Prix Nobel de chimie 2025, Omar Yaghi est arrivé à Bruxelles pour participer au 27e Conseil de Chimie Solvay. Le chercheur jordano-américain et figure de la chimie contemporaine est depuis de nombreuses années étroitement lié aux Instituts Solvay, fondés par l'ULB, la VUB et la famille Solvay.

2025, Omar Yaghi est arrivé à Bruxelles pour participer au 27e Conseil de Chimie Solvay. Le chercheur jordano-américain et figure de la chimie contemporaine est depuis de nombreuses années étroitement lié aux Instituts Solvay, fondés par l'ULB, la VUB et la famille Solvay. Lauréat du Prix Nobel de chimie 2025, Omar Yaghi entretient depuis plusieurs années des liens privilégiés avec les Instituts Solvay fondés par l'Université libre de Bruxelles, la Vrije Universiteit Brussel et la famille Solvay. Membre du Comité scientifique international de chimie, ancien titulaire d'une chaire aux Instituts Solvay, il participe activement à la définition des grandes orientations des célèbres Conseils Solvay.

Professeur à l'Université de Californie à Berkeley, Omar Yaghi a été titulaire en 2021 de la Chaire Solvay de chimie. Trois ans plus tard, il a reçu le prix Ernest Solvay de chimie, souvent considéré comme une étape annonciatrice du Nobel. Son travail sur les " architectures moléculaires " ouvre la voie à des applications innovantes pour piéger le $CO_2$, purifier l'eau ou extraire l'humidité de l'air, plaçant la chimie au service d'un monde plus durable.

## Press and newspapers

Ce mercredi 8 octobre, le brillant scientifique était à Bruxelles pour participer au 27e Conseil Solvay de chimie ("27th Solvay Conference on Chemistry"), qui réunit cette semaine les figures majeures du domaine. Lors d'une conférence de presse, il s'est exprimé aux côtés du physicien belge Marc Henneaux, professeur à l'ULB et Managing Director des Instituts Solvay.

Le 27e Conseil Solvay de chimie se terminera le dimanche 12 octobre par les Solvay Public Lectures – Exploring Frontiers in Chemistry, organisée dans le Studio 4 à Flagey. L'événement, accessible gratuitement sur inscription, réunira un large panel de chercheurs internationaux.

## Daily Science - 12.10.2025

### UN DES LAURÉATS DU PRIX NOBEL DE CHIMIE EN BELGIQUE

La semaine a été rythmée par l'annonce de différents Prix Nobel, dont les prix de médecine ou physiologie, de physique et de chimie. Parmi les lauréats de cette année, le Pr Omar Yaghi (chimie) a appris la bonne nouvelle alors qu'il se rendait... à Bruxelles.

En chimie, les pères des MOF mis à l'honneur

Le Prix Nobel de chimie 2025 a pour sa part été décerné à Susumu Kitagawa, Richard Robson et Omar M. Yaghi pour le développement d'une nouvelle architecture moléculaire : les réseaux métallo-organiques (dont l'acronyme est MOF, en anglais). Ces matériaux sont constitués d'ions métalliques liés par de longues molécules organiques, formant des structures cristallines poreuses avec de grandes cavités. Ces cavités permettent à des molécules de circuler librement à l'intérieur, ouvrant la voie à de nombreuses applications.

Les MOF peuvent être conçus sur mesure pour capturer ou stocker des substances spécifiques, comme le dioxyde de carbone, l'hydrogène ou des polluants. Ils peuvent aussi catalyser des réactions chimiques, conduire l'électricité, ou récolter de l'eau dans des environnements très secs, comme les déserts. Aujourd'hui, des dizaines de milliers de MOF différents ont été développés. Certains sont en cours d'étude pour relever des défis majeurs comme la dépollution de l'eau, la réduction des gaz à effet de serre, ou le stockage d'énergie. Ces recherches ouvrent des perspectives inédites pour les matériaux du futur.

À noter : le jour de l'annonce du prix Nobel de Chimie (le mercredi 8 octobre dernier), Omar M. Yaghi arrivait en Belgique pour participer au 27e Conseil de Chimie Solvay, organisé par les Instituts Solvay (ULB-VUB). Le Pr Yaghi est membre de son comité scientifique international de chimie et est également un ancien titulaire d'une chaire aux Instituts.

Le scientifique venait d'atterrir à Francfort, en provenance des Etats-Unis, quand il a reçu mercredi matin l'appel du Comité Nobel lui annonçant la nouvelle, juste avant que l'information ne devienne publique. De quoi rendre le dernier tronçon de son voyage vers Bruxelles encore plus palpitant !

# Press and newspapers

## De Standaard - 12.10.2025



# "Zuiver wetenschappelijk is het klimaatprobleem oplosbaar"

**INTERVIEW OMAR YAGHI** De Nobelprijs Chemie ging afgelopen week naar een bijzondere uitvinding: MOF's, een nieuwe klasse van materialen, zouden honderd-en-een problemen kunnen oplossen. Ook bijzonder is het levensverhaal van de uitvinder, Omar Yaghi. Met de hulp van de wetenschap realiseerde hij zijn American dream.

Frankfurt, afgelopen woensdag, halfelf 's ochtends. Een vliegtuig uit San Francisco is net geland en tot stilstand gekomen bij de gate. Terwijl ze wachten tot de deuren opengaan, checken passagiers hun smartphone op nieuwe berichten. Een man krijgt een oproep. Een nummer uit Zweden, toont zijn scherm. "Mijn studenten hadden gelijk", denkt hij bij zichzelf als hij opneemt. Het is iemand van het Nobelcomité, met de boodschap dat ze hem de Nobelprijs willen geven.

De man die als Nobellaureaat het vliegtuig uitstapte, is Omar Yaghi, professor scheikunde aan de Universiteit van Californië, in Berkeley. Hij deelt de Nobelprijs Chemie met twee andere scheikundigen voor de uitvinding van een geheel nieuwe klasse van materialen: *metal-organic frameworks* ('metaal-organische raamwerken'), of iets makkelijker: MOF's. Het zijn materialen waaraan immens potentieel wordt toegedicht: van het verwijderen van $CO_2$ uit de atmosfeer over het winnen van water uit woestijnlucht tot het wegfilteren van stoffen zoals PFAS. De mogelijke toepassingen zijn schier eindeloos. Niet voor niets worden MOF's weleens de materialen van de 21ste eeuw genoemd.

Yaghi wordt gezien als de vader van het MOF-onderzoeksveld. Zijn Nobelprijs is geen verrassing, het stond zo goed als vast dat hij hem ooit zou krijgen – dat wisten zijn studenten ook. Wat wel opvalt, is zijn levensverhaal: dat van een arme immigrant die zijn American dream realiseert.

De kersverse Nobellaureaat werd in 1965 geboren in Amman, de hoofdstad van Jordanië, als kind van gevluchte Palestijnen. Het kroostrijke gezin had het niet breed, wat zacht uitgedrukt is. In een telefonisch interview met de Nobelstichting vertelde Yaghi dat ze hun huis moesten delen met het vee dat ze hielden. Elektriciteit was er niet. Water was gerantsoeneerd en als de voorraad op was, was het wachten tot de volgende levering. Maar de jonge Omar ging wel naar school, ook al moest hij er elke dag kilometers voor wandelen.

### Schoonheid van moleculen

Hij was al vroeg gefascineerd door scheikunde. Als tienjarige had hij in een boek in de bibliotheek voor het eerst moleculen gezien – zoals ze meestal worden voorgesteld, als sterk uitvergrote modellen van bolletjes (de atomen) en staafjes (de bindingen tussen de atomen). Sindsdien heeft "de schoonheid van moleculen" hem niet meer losgelaten, zei hij in zijn eerste interview als Nobellaureaat. "Onze wereld is opgebouwd uit moleculen. Dat heb ik altijd willen doorgronden. Ik was er niet op uit om wereldproblemen op te lossen, zoals klimaatverandering of waterschaarste. Ik wilde mooie dingen maken en intellectuele vraagstukken oplossen."

Dat zou hij niet in zijn geboorteland Jordanië doen, maar wel in Amerika. Omdat hij duidelijk wat in zijn mars had, werd hij op zijn vijftiende met een paar duizend dollar op zak – het spaargeld van zijn vader, die een beenhouwerij had – naar de Verenigde Staten gestuurd om er te gaan studeren en werken. Studies aan betaalbare publieke scholen en staatsuniversiteiten leidden in 1990 tot een doctoraat in de chemie. In een reactie op zijn Nobelprijs benadrukt Yaghi het belang van dat publieke onderwijssysteem in de VS.

Vandaag is hij nog steeds aan een publieke universiteit verbonden (Berkeley), een die zeer hoog staat aangeschreven. Met Yaghi haalt de Californische universiteit al haar 28ste Nobelprijs binnen. Maar Berkeley moest deze week wachten, want haar nieuwste prijsbeest was dus in Europa. In Frankfurt stapte Yaghi over op een vlucht naar Brussel. Hij was immers op weg naar de Solvay Conferentie, een jaarlijkse bijeenkomst van topwetenschappers, afwisselend in de fysica en de chemie, waar de stand van zaken in het vakgebied wordt besproken – beroemd is de conferentie van 1927, toen Albert Einstein en Niels Bohr er bakkeleiden over de prille kwantummechanica. Yaghi dacht er niet aan om in Frankfurt rechtsomkeer te maken nadat hij dat onvergetelijke telefoontje uit Stockholm had gekregen. "Dit is een van de beste conferenties in de chemie. Hier kunnen we heel openlijk discussiëren, onder collega's en vrienden", aldus de Nobelprijswinnaar donderdag tijdens een interview met *De Standaard*.

**U bent nu wel de ster van deze bijeenkomst. En dat voor iemand die in armoedige omstandigheden is opgegroeid.**

"Dat heb ik aan mijn ouders te danken. Zij hebben me naar Amerika gestuurd. Ik wilde dat niet. Liever bleef ik in mijn geboorteland, om daar verder te studeren en werk te vinden. Welke vijftienjarige kiest er nu voor om zijn thuis en familie achter te laten?" Maar uiteindelijk was het een goede beslissing. Ik heb veel aan de wetenschap te danken. Ik noem het de grootste gelijkmakende kracht in de wereld. Daarmee bedoel ik dat iedereen eraan kan deelnemen. Wetenschap verbindt. Als ik hier een chemische formule opschrijf, wordt die begrepen door scheikundigen in Japan, China en Rusland."

**U ziet schoonheid in de chemie, meer bepaald in moleculen. Waarin zit die precies?**

"Scheikundigen proberen controle te krijgen over de materie op het niveau van haar bouwstenen, de atomen en moleculen. We zijn de enigen die nieuwe materialen maken, zoals MOF's – het is dus best een bijzonder beroep. In mijn domein doen we dat bottom-up, met atomen en moleculen als bouwblokjes, zoals in de molecuulmodellen met bolletjes en staafjes. Uit de structuren die zo ontstaan, spreekt voor mij veel schoonheid."

"Maar zo ging het er in de chemie heel lang niet aan toe. Onderzoek naar nieuwe materialen en stoffen gebeurde vaak lukraak: je mixte ingrediënten, je verwarmde het mengsel en dan bekeek je het resultaat. Dat vond ik geen bevredigende aanpak. Je had geen controle over wat je maakte, en het leverde geen mooie moleculaire structuren op. Zodra ik als onafhankelijke onderzoeker aan de slag kon (*aan de Arizona*

Omar Yaghi heeft een MOF gemaakt waarmee hij water uit woestijnlucht kan oogsten. © rr

> "Wetenschap is de grootste gelijkmaker in de wereld. Iedereen kan eraan deelnemen.
> Als ik hier een chemische formule opschrijf, wordt die begrepen door scheikundigen in Japan, China en Rusland"

## 50th Anniversary of ULB's *Campus de la Plaine*

In 2025, the University of Brussels (ULB) celebrated the 50th anniversary of the "Campus de la Plaine", which was inaugurated in 1975.

As one of the first occupants of the campus where they moved as soon as it opened, the International Solvay Institutes naturally took part in the celebrations.


Various posters explaining the mission of the Institutes and describing their rich history were exhibited. In particular, one poster illustrated the events that took place in the Solvay room in the last 50 years where many eminent scientists, including Nobel laureates in physics and chemistry, delivered lectures, contributing to the visibility of the campus.

## From the archives

### Solvay Conferences on Chemistry

| | |
|---|---|
| 1922 | Five topical questions in chemistry |
| 1925 | Chemical structure and activity |
| 1928 | Topical questions in chemistry |
| 1931 | Constitution and configuration of organic molecules |
| 1934 | Oxygen: chemical and biological reactions |
| 1937 | Vitamins and Hormones |
| 1947 | Isotopes |
| 1950 | Oxidation mechanism |
| 1953 | Proteins |
| 1956 | Some problems in mineral chemistry |
| 1959 | Nucleoproteins |
| 1962 | Energy transfer in gases |
| 1965 | Reactivity of the Photoexcited Organic Molecule |
| 1969 | Phase Transitions |
| 1972 | Electrostatic Interactions and Structure of Water |
| 1976 | Molecular Movements and Chemical Reactivity as conditioned by Membranes, Enzymes and other Molecules |
| 1980 | Aspects of Chemical Evolution |
| 1983 | Design and Synthesis of Organic Molecules Based on Molecular Recognition |
| 1987 | Surface Science |
| 1995 | Chemical Reactions and their Control on the Femtosecond Time Scale |
| 2007 | From Non-covalent Assemblies to Molecular Machines |

| | |
|---|---|
| 2010 | Quantum effects in chemistry and biology |
| 2013 | New Chemistry and New Opportunities from the Expanding Protein Universe |
| 2016 | Catalysis in Chemistry and Biology |
| 2019 | Computational Modeling: From Chemistry to Materials to Biology |
| 2022 | Chemistry Challenges of the 21st Century |
| 2025 | Exploring Frontiers in Chemistry |

## Chairs of the International Scientific Committee for Chemistry

| | |
|---|---|
| 1922 - 1939 | Sir William Pope<br>Cambridge, UK |
| 1945 - 1958 | Paul Karrer<br>1937 Nobel Laureate in Chemistry<br>Zurich, Switzerland |
| 1958 - 1988 | Alfred Ubbelohde<br>London, UK |
| 1989 - 2011 | Stuart Rice<br>Chicago, USA |
| 2011 - 2022 | Kurt Wüthrich<br>2002 Nobel Laureate in Chemistry<br>Zurich, Switzerland and La Jolla, USA |
| 2022 - present | Ben Feringa<br>2016 Nobel Laureate<br>Groningen, The Netherlands |

## Solvay Conferences on Physics

| | |
|---|---|
| 1911 | Radiation theory and the quanta |
| 1913 | The structure of matter |
| 1921 | Atoms and electrons |
| 1924 | Electric conductivity of metals |
| 1927 | Electrons and photons |
| 1930 | Magnetism |
| 1933 | Structure and properties of the atomic nuclei |
| 1948 | Elementary particles |
| 1951 | Solid state |
| 1954 | Electrons in metals |
| 1958 | The structure and evolution of the universe |
| 1961 | Quantum Field Theory |
| 1964 | The structure and evolution of galaxies |
| 1967 | Fundamental problems in elementary particle physics |
| 1970 | Symmetry properties of nuclei |
| 1973 | Astrophysics and gravitation |
| 1978 | Order and fluctuations in equilibrium and nonequilibrium statistical mechanics |
| 1982 | Higher energy physics: What are the possibilities for extending our understanding of elementary particles and their interactions to much greater energies? |
| 1987 | Surface science |
| 1991 | Quantum optics |
| 1998 | Dynamical systems and irreversibility |

## From the archives

| | |
|---|---|
| 2001 | The physics of communication |
| 2005 | The quantum structure of space and time |
| 2008 | Quantum theory of condensed matter |
| 2011 | The theory of the quantum world |
| 2014 | Astrophysics and Cosmology |
| 2017 | The Physics of Living Matter: Space, Time and Information in Biology |
| 2022 | The Physics of Quantum Information |
| 2023 | The Structure and Dynamics of Disordered |

## Chairs of the International Scientific Committee for Physics

| | |
|---|---|
| 1911 - 1928 | Hendrik Lorentz<br>1902 Nobel Laureate in Physics<br>Haarlem, The Netherlands |
| 1928 - 1946 | Paul Langevin,<br>Paris, France |
| 1946 - 1962 | Sir Lawrence Bragg<br>1915 Nobel Laureate in Physics,<br>Cambridge, UK |
| 1962 - 1967 | Robert Oppenheimer<br>Princeton, USA |
| 1967 - 1968 | Christian Møller<br>Copenhagen, Denmark |
| 1969 - 1980 | Edoardo Amaldi<br>Rome, Italy |
| 1980 - 1990 | Léon Van Hove<br>Genève, Switzerland |
| 1992 - 2006 | Herbert Walther<br>Munich, Germany |
| 2006 - present | David Gross<br>2004 Nobel Laureate in Physics,<br>Santa Barbara, USA |

## Solvay Conference on Biology

| | |
|---|---|
| 2024 | The organisation and dynamics of biological computation |

# Solvay Public Lectures

## 22 June 2005

*"From Quarks to the Quantization of Gravitation: Challenges and Obstacles in our Search for the Fundamental Forces"*
by Gerard 't Hooft (Utrecht)
1999 Nobel Laureate in Physics

*"From Structural Biology to Structural Genomics: New Challenges for Physics and Chemistry in the Post-Genomic Era"*
by Kurt Wüthrich (Zurich and La Jolla)
2002 Nobel Laureate in Chemistry

## 4 December 2005

*"Strings, Black Holes and the End of Space and Time"*
by Robbert Dijkgraaf (Amsterdam)

*"The Fabric of the Cosmos, Space, Time and the Texture of Reality"*
by Brian Greene (New York)

## 20 May 2007

*"The Origin of the Universe"*
by Stephen Hawking (Cambridge, UK)

*"Architecture in Nanospace"*
by Harold Kroto (Brighton)
1996 Nobel Laureate in Chemistry

## 2 December 2007 | "Chemistry? More than ever!"

*" De la Matière à la Vie: la Chimie ? La Chimie ! "*
by Jean-Marie Lehn (Paris and Strasbourg)
1987 Nobel Laureate in Chemistry

## 12 October 2008 | "Images from the Quantum World"

*"New Forms of Quantum Matter near Absolute Zero Temperature"*
by Wolfgang Ketterle (Cambridge, USA)
2001 Nobel Laureate in Physics

*"Visualizing Complex Electronic Quantum Matter at Atomic Scale"*
by J.C. Seamus Davis (Ithaca, USA)

## 4 October 2009

*" VIH/SIDA, une aventure scientifique et humaine en réponse à une épidémie émergente "*
by Françoise Barré-Sinoussi (Paris)
2008 Nobel Laureate in Medecine

## 17 October 2010 | "Chemistry: at the crossroads of Physics and Biology"

*"The magnetic compass of birds and its physical basis"*
by Wolfgang Wiltschko (Frankfurt am Main)

*"Experimental surprises and their solutions in theory"*
by Rudolph Marcus (Pasadena)
1992 Nobel Laureate in Chemistry

## 23 October 2011 | "The Future of Physics"

*"Time and Einstein in the $21^{st}$ century"*
by William Phillips (College Park)
1997 Nobel Laureate in Physics

*"Quantum Beauty"*
by Frank Wilczek (Cambridge, USA)
2004 Nobel Laureate in Physics

## 21 October 2012

*"The Science of Simplicity"*
by George Whitesides (Cambridge, USA)

*"Will our Thinking Become Quantum-Mechanical?"*
by Michael Freedman (Santa Barbara)
1986 Recipient of the Fields Medal

*"Exploring the Postgenomic Protein Universe"*
by Kurt Wüthrich (Zurich and La Jolla)
2002 Nobel Laureate in Chemistry

## Solvay Public Lectures

### 20 October 2013

*"How proteins are made in the cell: Visualizing the ribosome in action"*
by Joachim Frank (Columbia University, USA)
2017 Nobel Laureate in Chemistry

*"Reprogramming the genetic code"*
by Jason Chin (University of Cambridge, UK)

### 12 October 2014

*"Starquakes and Exoplanets in our Milky Way galaxy"*
by Conny Aerts (KU Leuven, Belgium)

*"From a 'simple'big bang to our complex cosmos"*
by Martin Rees (University of Cambridge, UK)

*"The Brout-Englert-Higgs mechanism and its scalar Boson"*
by François Englert (ULB, Belgium)
2013 Nobel Laureate in Physics

### 18 October 2015 | "One hundred years of Einstein's general relativity"

*"Massive Black Holes and the Evolution of Galaxies"*
by Reinhard Genzel (Max Planck Institute Munich, Germany)
2020 Nobel Laureate in Physics

*"From Nothing to the Universe"*
by Viatcheslav Mukhanov (LMU Munich, Germany)

### 23 October 2016 | "Chemistry for the World of Tomorrow"

*"Translation of Academic Science into the Commercial"*
by Robert Grubbs (California Institute of Technology, USA)
2005 Nobel Laureate in Chemistry

*"The Art of Building Small"*
by Ben Feringa (University of Groningen, The Netherlands)
2016 Nobel Laureate in Chemistry

## 22 October 2017 | "Frontiers of Science from Physics to Biology"

*"From Genes to Cell Shape: The Mechanics of Embryonic Development"*
by Eric Wieschaus (Princeton U., USA)
1995 Nobel Laureate in Physiology or Medicine

*"The Many Frontiers of Physics"*
by David Gross (Kavli Institute, USA)
2004 Nobel Laureate in Physics

## 21 October 2018

*"De novo protein design: bringing biology out of the Stone Age"*
by David Baker (University of Seattle, USA)
2024 Nobel Laureate in Chemistry

*"Random Walk to Graphene"*
by Andre Geim (University of Manchester, UK)
2010 Nobel Laureate in Physics

## 20 October 2019 | "Frontiers of Chemistry"

*"Optical microscopy: the resolution revolution"*
by Stefan Hell (Max Planck Institute, Göttingen, Germany)
2014 Nobel Laureate in Chemistry

*"To get to know biological molecules, freeze them and photograph them!"*
by Eva Nogales (UC Berkeley, USA)

## 12 September 2021 | "Physics, Chemistry and Life Sciences"

*"How personalised is your immune repertoire?"*
by Aleksandra Walczak (ENS, Paris, France)

*"Why we cannot make artificial life in a laboratory"*
by Bert Meijer (Eindhoven, The Netherlands)

*"Steps towards complex matter: chemistry!"*
by Jean-Marie Lehn (Strasbourg, France)
1987 Nobel Laureate in Chemistry

## Solvay Public Lectures

### 24 October 2021

*"Exoplanets or the Quest for Life around Another Sun"*
by Michaël Gillon (Liège University, Belgium)

### 22 May 2022 | "The New Quantum Revolution"

*"The Strangeness and the power of quantum physics"*
by Serge Haroche (Collège de France, Paris)
2012 Nobel Laureate in Physics

*"Quantum computing and the entanglement frontier"*
by John Preskill (Caltech, USA)

### 16 October 2022

*"Water Harvesting from Air Anytime Anywhere"*
by Omar Yaghi (Berkeley, USA)
2025 Nobel Laureate in Chemistry

*"What is Life?"*
by Paul Nurse (Crick Institute, UK)
2001 Nobel Laureate in Medicine

## 22 October 2023 | "Complex systems and collective behaviors"

*"Computational optimization: from glasses to black holes"*
by Leticia Cugliandolo (Sorbonne Université, Paris)

*"How many candies are in that jar? A dynamical phase transition"*
by Paul Chaikin (New York University)

## 21 April 2024

*"Seeing what's coming"*
by Stephanie Palmer (University of Chicago, USA)

*"The Social life of a cell"*
by Anthony Hyman (Max-Planck-Institute, Germany)

## 12 October 2025

*"Peptides – Molecular Allrounders"*
by Helma Wennemers (ETH, Zurich)

*"Reading your DNA: What does it tell us"*
by Shankar Balasubramanian (University of Cambridge)

## Syensqo Chairs in Chemistry by the International Solvay Institutes

| | |
|---|---|
| 2008 | Richard Saykally, Berkeley, USA |
| 2009 | Alexander Mikhailov, Berlin, Germany |
| 2010 | Weitao Yang, Durham, USA |
| 2011 | Jean-Luc Brédas, Atlanta, USA |
| 2012 | Viola Vogel, Zurich, Switzerland |
| 2013 | Egbert Meijer, Eindhoven, The Netherlands |
| 2014 | Richard Royce Schrock, 2005 Nobel Laureate in Chemistry, MIT, USA |
| 2015 | Andreas Manz, Saarbrücken, Germany |
| 2016 | Raymond Kapral, Toronto, Canada |
| 2017 | Richard Henderson, 2017 Nobel Laureate in Chemistry, Cambridge, UK |
| 2018 | Ben Feringa, 2016 Nobel Laureate in Chemistry, U. of Groningen, The Netherlands |
| 201 | Gernot Frenking, Philipps-U. Marburg, Germany |
| 2020 | Joanna Aizenberg, Harvard, USA |
| 2021 | Omar Yaghi, Berkeley, USA<br>2025 Nobel Laureate in Chemistry |
| 2022 | Daniel Jacob, Harvard University, USA |
| 2023 | Ehud Gazit, Tel-Aviv University, Israel |
| 2024 | Markus Antonietti, Potsdam, Germany |
| 2025 | Laura Gagliardi, University of Chicago, USA |

## Jacques Solvay Chairs in Physics

2006 Ludwig Faddeev, St. Petersburg, Russia

2007 Michael Berry, Bristol, UK

2008 David Gross, Santa Barbara, USA, 2004 Nobel Laureate in Physics

2009 Valery Rubakov, Moscow, Russia

2010 Serge Haroche, Paris, France, 2012 Nobel Laureate in Physics

2011 Nathan Seiberg, Princeton, USA

2012 Jan Zaanen, Leiden, The Netherlands

2013 Gian Giudice, CERN, Switzerland

2014 Viatcheslav F. Mukhanov, LMU Munich, Germany

2015 Peter Zoller, Innsbruck, Austria

2016 Dam Thanh Son, Chicago, USA

2017 Uri Alon, Rehovot, Israel

2018 Bernard Derrida, Collège de France, France

2019 Gary Gibbons, Cambridge, UK

2020 Roger Blandford, Stanford University, USA

2021 Jean Dalibard, Collège de France, France

2022 Juna Kollmeier, Canadian Institute for Theoretica Astrophysics, Toronto, Canada

2023 Subir Sachdev, Harvard University, USA

2024 Samaya Nissanke, Amsterdam, The Netherlands

2025 Vyacheslav Rychkov, IHES, Bures-sur-Yvette, France

# The international Solvay Chairs in Physics and in Chemistry

## International Solvay Chair in Biology

2025 Benjamin Simons, Cambridge University, UK

## 2011 Solvay Centenary Chair

David Gross
2004 Nobel Laureate in Physics,
Santa Barbara, USA

## New Horizon Lectures

### Chemistry

| | |
|---|---|
| 2018 | Alexandre Tkatchenko, University of Luxembourg |
| 2019 | Rafal Klajn, Weizmann Institute, Israel |
| 2020 | Hans Jakob Wörner, ETH Zurich, Switzerland |
| 2021 | Ying Diao, University of Illinois, USA (postponed in 2023) |
| 2022 | Cornelia Meinert, CNRS, Université Côte d'Azur, France |
| 2023 | Danna Freedman, MIT, USA |
| 2024 | Alexis Komor, University of California, San Diego, USA |
| 2025 | Todd Gingrich, Northwestern University, USA |

### Physics

| | |
|---|---|
| 2018 | Zohar Komargodski, Weizmann Institute, Israel & Simons Center University of NY, Stony Brook, USA |
| 2019 | Aleksandra Walczak, LPT ENS, Paris, France |
| 2020 | Douglas Stanford, Stanford University, California, USA |
| 2021 | Maria Bergemann, Max Planck Institute, Heidelberg, Germany |
| 2022 | Nir Navon, Yale University, USA (postponed in 2023) |
| 2023 | Alexander Zhiboedov, CERN, Genève, Switzerland |
| 2024 | Netta Engelhardt, MIT, USA |
| 2025 | Kareem J. El-Badry, Caltech, USA |

# Presidents and directors

Ernest Solvay, his son Armand Solvay and his grand-son Ernest-John Solvay successively presided over the destiny of the International Solvay Institutes until 1958. In 1958, the Institutes were restructured with the creation of the positions of "President" and "Director".

## Presidents

| | |
|---|---|
| 1958 - 2010 | Jacques Solvay |
| 2010 - present | Jean-Marie Solvay |

## Directors

| | |
|---|---|
| 1958 - 2003 | Ilya Prigogine<br>1977 Nobel Laureate in Chemistry<br>Professor ULB |
| 2003 - 2004 | André Jaumotte<br>Honorary Rector<br>and Honorary President ULB |
| 2004 - present | Marc Henneaux<br>Professor ULB and Collège de France |

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