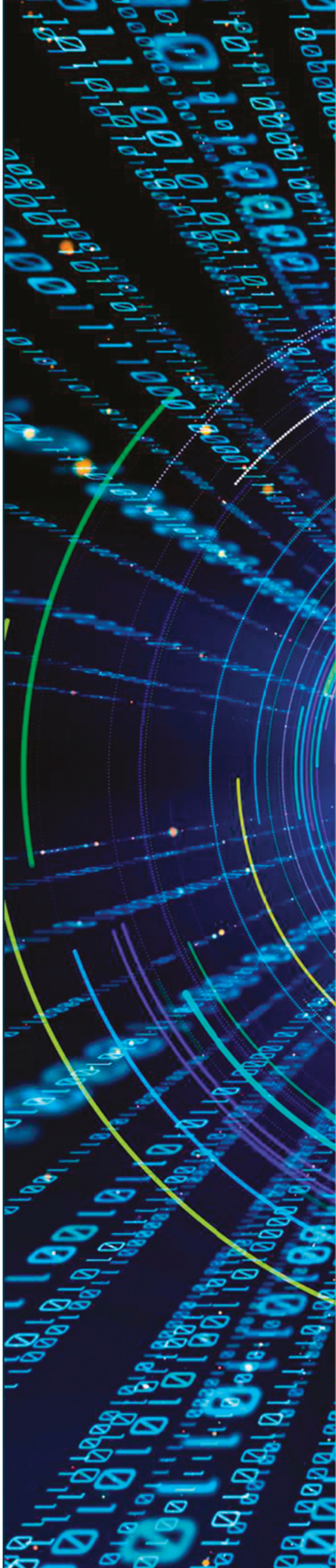
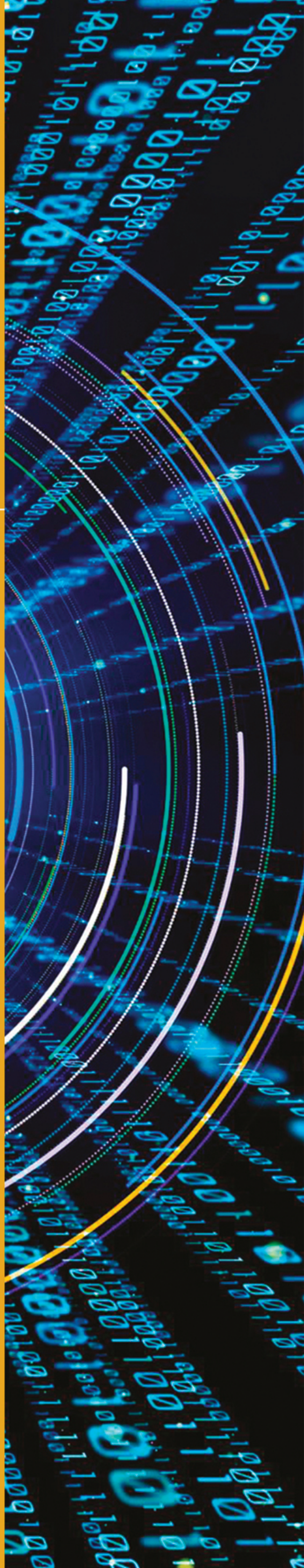


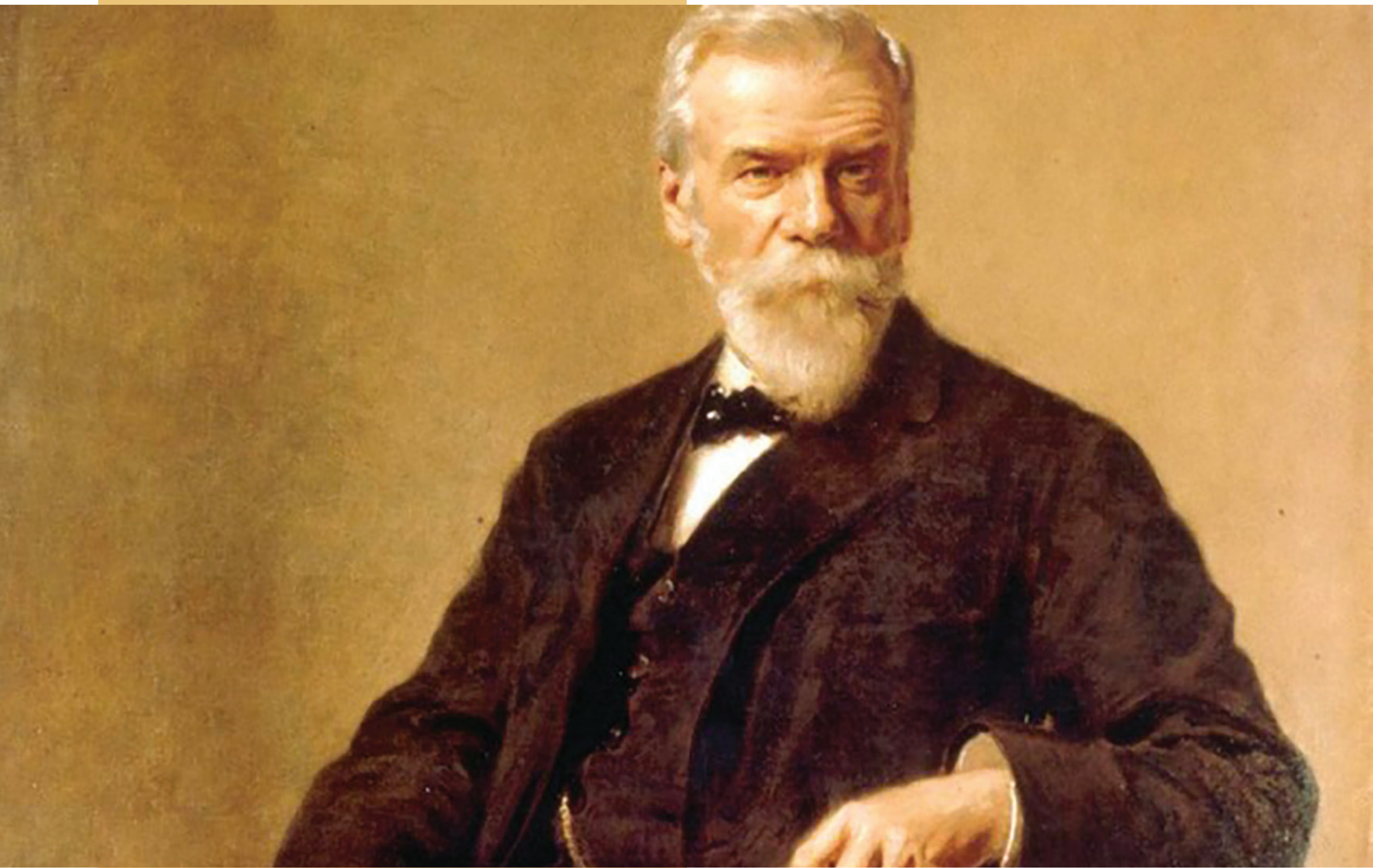
# ANNUAL REPORT

# 2019



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

Internationale Instituten
voor Fysica en Chemie
gesticht door
Ernest Solvay VZW



# ERNEST SOLVAY

There are no limits
to what science
can explore

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

# THE SOLVAY FAMILY


Loterie Nationale
Nationale Loterij
2019 Solvay Public Lectures
Sunday 20 October 2019 at 15:00
Flagey Studio 4 | Brussels
VIP ENTRANCE
FRONTIERS
OF CHEMISTRY
Optical microscopy:
the resolution revolution
Professor Stefan Hell
To get to know biological molecules, freeze them and photograph them!
Professor Eva Nogales
Panel discussion chaired by
Prof. Bert Weckhuysen
with the participation of
Profs. Stefan Hell, Eva Nogales,
Veronique Van Speybroeck, Julia Yeomans.


MINFLUX


Thank you to the Institutions below for their support:
ULB
VUB
SOLVAY
Loterie Nationale Loterij
FEDERATION WALLONIE-BRUXELLES
be.brussels
SOLVAY FAMILY
RICHTING MORGEN
Met steun van de Vlaamse overheid

# 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 and physicists 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 to 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.

Loterie Nationale Loterij

# CONTENTS

Jean-Marie Solvay, great-great-grandson of Ernest Solvay

# THE YEAR 2019

The year 2019 was another full year of reoccurring activities. In particular, a Chemistry conference was held this year. The conference was very interesting because it shone the light of artificial intelligence and modelling on domains of chemistry as diverse as functional materials to biological cells. As usual, listening to distinguished experts from diverse fields exchanging insights was fascinating. My special thanks go to professors Kurt Wüthrich, Bert Weckhuysen and Anne De Wit for the preparation and the organization of the conference.

The various activities organized with the Belgian universities in support of curiosity driven research are numerous and dynamic. They are outlined in the following pages. I hope that readers of this report will delight in the diversity of the subjects that were proposed to the student communities. Special thanks go to the members of the Local Scientific Committees for their insight and council as to the organizers, friends of the Institutes.

# A WORD
## FROM THE PRESIDENT

This year we had three outliers in respect to our regular activities.

The first one was the Mimifest which was, as scientists like to do it, an extraordinary series of presentations, given by very distinguished personalities, celebrating the Institutes and the contribution that Mimi Solvay (my mother) has given over 65 years to the various conferences. I must say that she has been an outstanding person, as an organizer, as a hostess and as a loyal supporter of the conferences. Mimi has met so many extraordinary geniuses over the years. She has supported the conferences, driven by her inextinguishable curiosity in human creativity. We are, at the Institutes incredibly grateful for her support. My special thanks go to Marc Henneaux and friends for their kind and generous attention in making this happen.

The second outlier this year was a conference which I had never attended: Strings 2019. The conference, an annual occurrence, brought to Brussels 500 participants from all over the world. As an outsider to the physics of string theory, the event was outstanding for the number of young participants. Significant also was the part: Science meets Art, with the panel session “Gravity in Dance” led by Robbert Dijkgraaf and the dance performance choreographed by Anne Teresa De Keersmaeker, “Mitten wir in Leben sind”. The organization of the event was perfectly led, thanks to Professor Marc Henneaux, Dominique Bogaerts and Isabelle van Geet. Special thanks go to Thomas Hertog who was instrumental for the “Gravity and Dance” event.

The third outlier was the event we gave for the VUB Fellows at the Maison Ernest Solvay, graciously made available by Solvay SA on November 26. It was an opportunity for the Institutes to meet unique personalities, friends of the VUB.

In the name of the board of directors and of all our donors, I would like to thank the director and his team for the outstanding work in making all these activities possible. My thanks also go to the members of our International Scientific Committees for their commitment and their guidance.

Jean-Marie Solvay
President

# A WORD
## FROM THE DIRECTOR

This report reviews in detail the scientific activities organized or supported by the International Solvay Institutes during the year 2019. These activities (25th Solvay Conference on Chemistry, international Chairs, "New Horizons Lectures", international conference "Strings 2019", workshops, colloquia, graduate school in theoretical physics and public event) attracted to Brussels hundreds of scientists and covered a wide spectrum of developments at the frontiers of physics and chemistry. As in previous years, a balance between physics and chemistry, and an opening towards promising emerging fields, inspired the 2019 program.

All the detailed information can be found in the core of the report. I will just briefly mention in this introductory section four salient events.

The major 2019 activity was the organization of the 25th Solvay Conference on Chemistry from 16-19 October 2019. Devoted to "Computational Modeling: From Chemistry to Materials to Biology", the meeting was a great scientific success. It attracted in Brussels about 45 leading scientists from all over the world who confronted their views on topics at the forefront of research as diverse as "Artificial Intelligence/Machine Learning in Chemistry", "Modeling of Functional Materials", "Models and Experimental Data on Water and Dynamic Complexity of Solid/Liquid Interfaces", "Computational Modeling in High-resolution Imaging", "Modeling of Non-equilibrium Systems and Simulation of Molecular Machines" and "Computers in Interactive Structural Biology Leading to Modeling of an Intact Biological Cell". The International Solvay Institutes are most grateful to the conference chairs, Professors Kurt Wüthrich and Bert Weckhuysen, for carrying the challenging task of scientifically organizing this superb conference.

As it is the tradition, the 25th Solvay Conference on Chemistry was followed by a public event on October 20, the theme of which was "Frontiers of Chemistry". Professors Stefan Hell and Eva Nogales delivered popular lectures on the spectacular developments that occurred in microscopy techniques, both optical and electronic, enabling scientists to explore the microscopic world with unprecedented accuracy. We thank the two lecturers for their crystal-clear and very inspiring talks.

Another major event was the "Mimi Fest: 65 years of indefectible commitment and dedicated support to the Solvay Institutes" that happened on July 8, to celebrate the unique role that Madame Solvay has played in the development of the Institutes. A one-day family-type event was organized in her honour, where outstanding scientists and friends associated with the Institutes paid tribute to her exceptional commitment. The meeting took place in the prestigious – and quite appropriate! - setting of the "Maison Ernest Solvay".

The International Solvay Institutes played also a leading role in the organization of the conference "Strings 2019". "Strings" is a series of annual conferences bringing together the world community working on string theory (an area of theoretical physics); it is the major conference in the field. Strings 2019 was organized in Brussels by a consortium of Belgian Theoretical Physics Groups from various universities (KULeuven & Kortrijk, UCL, University of Ghent, ULB, University of Mons, VUB) conducted by the International Solvay Institutes. It was attended by 500 participants.

Besides the activities of the Institutes, the report describes the research carried in the groups of the Director and of the deputy-Director. The research highlights of other researchers connected with the Institutes are also outlined.

The research of the group of the Director benefited from the direct and most precious support of the Solvay family and the Solvay group. I heartily thank them.

The activities described in this report would not have been possible without the help of the sponsors of the International Solvay Institutes, to whom I would like to express our gratitude. These are the Université Libre de Bruxelles, the Vrije Universiteit Brussel, the Solvay company, the Belgian National Lottery, the Brussels-Capital Region, the Fédération Wallonie-Bruxelles, the Vlaamse Regering, and last but not least – and as recalled above -, the Solvay family who continues with the same conviction a more than a century-old tradition of support to fundamental research.

The remarkable efficiency and dedicated commitment of Dominique Bogaerts and Isabelle Van Geet in the management of the activities of the Institutes, is again gratefully acknowledged.

Marc Henneaux
Director

# GENERAL INFORMATION

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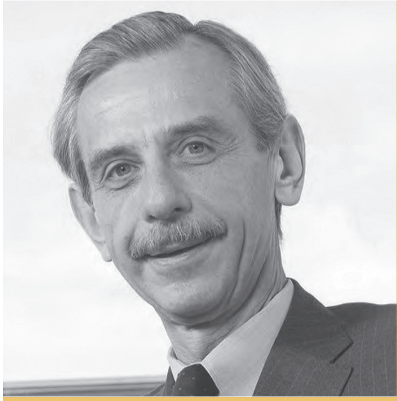

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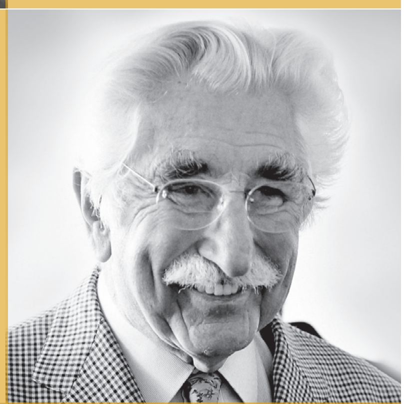

**Eddy Van Gelder**
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Former Deputy Director for Chemistry
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Scientific Secretary of the International
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Marc Henneaux
Professor ULB | Director

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

Marina Solvay

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

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## AND STAFF

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ULB
Director

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Deputy Director for Physics
Secretary of the International Scientific Committee for Physics

Professor Gert Desmet
VUB
Deputy Director for Chemistry

Professor Glenn Barnich | ULB
Solvay Colloquia in Physics

Professor Ben Craps | VUB
Doctoral School

Professor Anne De Wit | ULB
Archives and Secretary of the International Scientific Committee for Chemistry

Professor Yves Geerts | ULB
Solvay Colloquia and New Horizons Lectures in Chemistry

The Director is assisted in his 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 him for the organization of all the other activities (workshops, colloquia, chairs, new horizons lectures).

He is assisted in his management tasks by the administrative staff:

- Ms Dominique Bogaerts
  Office manager
- Ms Isabelle Van Geet
  Project coordinator
- Ms Chantal Verrier
  Mr Tahar Hmida *(from October)*
  Accounting officers

# INTERNATIONAL SCIENTIFIC COMMITTEE
## FOR PHYSICS

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. Members are appointed for a 6-year period term, renewable once.

## CHAIR

Professor David Gross
*2004 Nobel Laureate*
Kavli Institute for Theoretical Physics
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Vrije Universiteit Brussel, Belgium

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Professor Roger Blandford
Stanford University, USA

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

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Professor Fabiola Gianotti
CERN, Switzerland

Professor Bertrand Halperin
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*2001 Nobel Laureate*
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# INTERNATIONAL SCIENTIFIC COMMITTEE
## FOR CHEMISTRY

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

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Université Libre de Bruxelles, Belgium

### MEMBERS

Professor Joanna Aizenberg
Harvard University, Cambridge, USA

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

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

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

Professor Robert H. Grubbs
*2005 Nobel Laureate*
California Institute of Technology, Pasadena, USA

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

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Massachusetts Institute of Technology
Cambridge, USA

Professor Bert Weckhuysen
University of Utrecht, The Netherlands

Professor George M. Whitesides
Harvard University, Cambridge, USA

# 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 the respective Scientific Committees), report to the Board of Directors and provide advice for future developments.

Members are appointed for a 6-year period term, renewable once.

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Chalmers University of Technology
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Golm, Germany

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Professor Jacques Prost
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Professor Gunnar von Heijne
Stockholm University, Sweden

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ULB, Brussels

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Professor Nicolas Boulanger I UMONS
Professor Ben Craps I VUB, Brussels
Professor Jan Danckaert I VUB, Brussels
Professor Pierre Gaspard I ULB, Brussels
Professor Jean-Marc Gérard I UCL, Louvain
Professor Joseph Indekeu I KU Leuven
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Professor Alexander Sevrin I VUB, Brussels
Professor Jacques Tempere I UAntwerp
Professor Petr Tinyakov I ULB, Brussels
Professor Christian Van den Broeck † I UHasselt
Professor Sophie Van Eck I ULB, Brussels
Professor Nicolas Vandewalle I ULg, Liège

### OBSERVER

Professor Anne De Wit I ULB, Brussels

## FOR CHEMISTRY

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Professor Gert Desmet
VUB, Brussels

### MEMBERS

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Professor Yves Geerts I ULB, Brussels
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Professor Marlies Van Bael I UHasselt
Professor Lode Wyns I VUB, Brussels

### OBSERVERS

Professor Pierre Gaspard I ULB, Brussels
Professor Marc Henneaux I ULB, Brussels

### IN MEMORIAM

*The International Solvay Institutes mourn the passing away of Christian Van den Broeck, Professor at the University of Hasselt, which occurred in early 2019. Christian was a remarkable physicist with exceptional curiosity and a great friend of the Institutes. He served on our "Local Committee for Physics" for many years contributing thereby to the vigour of our scientific activities. He was one of the main organizers of various successful Solvay workshops. We will deeply miss his precious advice and long lasting friendship.*

# HONORARY MEMBERS

Professor Fortunato Tito Arecchi
Università di Firenze and INOA, Italy

Professor Claudio Bunster
Centro de Estudios Científicos,
Valdivia, Chile

Professor Claude Cohen-Tannoudji
*1997 Nobel Laureate*
Ecole Normale Supérieure, Paris,
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*1967 Nobel Laureate*
Max-Planck Institut, Göttingen,
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*2013 Nobel Laureate*
Université Libre de Bruxelles, Belgium

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University of Berkeley, USA

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*1999 Nobel Laureate*
Spinoza Instituut, Utrecht,
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Landau Institute of Theoretical
Physics, Moscow, Russia

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Stanford University, USA

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*1987 Nobel Laureate*
Collège de France, Paris, France

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Utrecht Universiteit, The Netherlands

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Moscow State University, Russia

Professor Mario J. Molina
*1995 Nobel Laureate*
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Cambridge, USA

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University of California, San Diego,
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University of Florida, Gainesville, USA

Professor Stuart Rice
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Belgium

Professor E.C.G. Sudarshan
University of Texas, Austin, USA

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

Professor Chen Ning Yang
*1957 Nobel Laureate*
Chinese University Hong Kong
& Tsinghua University, Beijing, China

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Van Camp Benjamin
Van den Broeck Christian †
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Wielemans Patrick
Willems Hans
Willox Ralph

# 25th SOLVAY CONFERENCE ON CHEMISTRY

OCTOBER 16-19 | 2019

# 25th SOLVAY CONFERENCE ON CHEMISTRY

## COMPUTATIONAL MODELING: FROM CHEMISTRY TO MATERIALS TO BIOLOGY

Computational modeling and artificial intelligence have invaded chemistry and hold great promise of further major advances.

The 25th Solvay Conference was devoted to these extremely active and challenging topics. The scope was broad, original and quite unusual since it covered all of chemistry but with a particular angle, that of the methods being used. Leading chemists from different horizons, combining a mix of theoreticians and experimentalists, discussed progress and perspectives in their own area in a manner enabling fruitful exchanges across disciplines.

The theme of the conference was chosen by the International Solvay Scientific Committee for Chemistry chaired by Nobel laureate Professor Kurt Wüthrich, from the Scripps Research Institute and the ETH.

The Conference took place at the hotel Metropole in Brussels from October 16 through October 19, 2019. It was chaired by Professor Kurt Wüthrich and co-chaired by Professor Bert Weckhuysen (Utrecht). Together with the chairs of the various sessions, they put up a program that met in a remarkable manner the challenges posed by the broad theme. The International Solvay Institutes express their deepest thanks to all of them for the definite success of the 25th Solvay Conference on Chemistry.

The 25th Solvay Conference on Chemistry is the 5th of the 21st century. The normal rhythm is one conference every 3 years, but this rhythm was interrupted by various factors in the past. The 3-year periodicity was resumed in 2007 and has been strictly adhered to since then. The next conference will take place in 2022. It will mark the 100th anniversary of the first Solvay Conference on Chemistry.

# SCIENTIFIC THEMES AND PROGRAMME

The 25th Solvay Conference addressed at length many frontier subjects:

- "Artificial Intelligence/Machine Learning in Chemistry",
- "Modeling of Functional Materials",
- "Models and Experimental Data on Water and Dynamic Complexity of Solid/Liquid Interfaces",
- "Computational Modeling in High-resolution Imaging",
- "Modeling of Non-equilibrium Systems and Simulation of Molecular Machines",
- "Computers in Interactive Structural Biology Leading to Modeling of an Intact Biological Cell",

leading to the very challenging following programme:

# PROGRAMME

### Wednesday 16 October 2019

Welcome addresses by Marc Henneaux, Director of the Solvay Institutes and by Kurt Wüthrich, Chair of the Scientific Committee for Chemistry of the International Solvay Institutes.

*Session 1: Artificial Intelligence/Machine Learning in Chemistry*

Chair: Kurt Wüthrich

Belgian Auditors: Bortolo Mognetti & Emilie Cauët

Introductory statements by Chair Kurt Wüthrich and Alán Aspuru-Guzik

Statements: Todd Martinez, Bartosz Grzybowski, Alán Aspuru-Guzik, Eugene Shakhnovich

Discussion among the panel members

General Discussion

*Session 2: Modeling of Functional Materials*

Chair: Bert Weckhuysen

Belgian Auditors: Frank De Proft & Yoann Olivier

Introductory statement by chair Bert Weckhuysen

Statements: Veronique Van Speybroeck, Lee Cronin, Berend Smit, Miquel Sola, Laura Gagliardi, Katarina Stanciakova

Discussion among the panel members

General Discussion

Reception at the Brussels City Hall

## Thursday 17 October 2019

*Session 3: Models and Experimental Data on Water and Dynamic Complexity of Solid/Liquid Interfaces*

Chair: Joanna Aizenberg

Belgian Auditors: Alain Jonas & Benoît Champagne

Introductory statement by chair Joanna Aizenberg

Statements: Sinan Keten, Julia Yeomans,
Angelos Michaelides, Mischa Bonn, David Quéré

Discussion among the panel members

General Discussion

*Session 4: Computational Modeling in High-resolution Imaging*

Chair: Stefan Hell

Belgian Auditors: Jeremy Harvey & Ruslan Efremov

Introductory statement by chair Stefan Hell

Statements: Raimund J. Ober, Matthew D. Lew,
Jörg Enderlein, Bernd Rieger, Yoav Shechtman,
Jan Huisken

Discussion among the panel members

General Discussion

## Friday 18 October 2019

*Session 5: Modeling of Non-equilibrium Systems and Simulation of Molecular Machines*

Chair: Ben Feringa

Belgian Auditors: Yannick De Decker & Geneviève Dupont

Introductory statement by chair Ben Feringa

Statements: Dean Astumian, Wilhelm Huck,
Annette Taylor, Bernd Hartke, Thomas Hermans,
Andreas Walther

Discussion among the panel members

General Discussion

Banquet at the Plaza Hotel

## Saturday 19 October 2019

*Session 6: Computers in Interactive Structural Biology Leading to Modelling of an Intact Biological Cell*

Chair: Thomas Cech

Belgian Auditors: Martine Prévost & Han Remaut

Introductory statement by chair Thomas Cech

Statements: Eva Nogales, Winfried Denk,
Xavier Darzacq, Markus Covert, Mark Ellisman

Discussion among the panel members

General Discussion

# PARTICIPANTS

The Solvay conferences are elitist conferences by invitation-only, with a limited number of participants. Discussions play a central role.

Aizenberg Joanna (Harvard University, Cambridge, USA)

Aspuru-Guzik Alán (University of Toronto, Canada)

Astumian Dean (University of Maine, Orono, USA)

Bonn Mischa (MPI for Polymer Research, Mainz, Germany)

Cech Thomas (University of Colorado, Boulder, USA)

Covert Markus (Stanford University, Palo Alto, USA)

Cronin Lee (University of Glasgow, UK)

Darzacq Xavier (University of California, Berkeley, USA)

De Wit Anne (ULB, Brussels, Belgium)

Denk Winfried (MPI of Neurobiology, Martinsried, Germany)

Ellisman Mark (University of California, San Diego, USA)

Enderlein Jörg (Göttingen University, Germany)

Feringa Ben (University of Groningen, The Netherlands)

Gagliardi Laura (University of Minnesota, Minneapolis, USA)

Grzybowski Bartosz (UNIST, Ulsan, Korea)

Hartke Bernd (University of Kiel, Germany)

Hell Stefan (MPI for Biophysical Chemistry, Göttingen, Germany)

Hermans Thomas (University of Strasbourg, France)

Huck Wilhelm (Radboud University, Nijmegen, The Netherlands)

Huisken Jan (Morgridge I. for Research, Madison, USA)

Keten Sinan (Northwestern University, Evanston, USA)

Lekkerkerker Henk (Utrecht University, The Netherlands)

Lew Matthew (Washington University, St. Louis, USA)

Martínez Todd (Stanford University, Palo Alto, USA)

Michaelides Angelos (University College London, UK)

Nogales Eva (University of California, Berkeley, USA)

Ober Raimund (Texas A&M University, College Station, USA)

Quéré David (ESPCI, Paris, France)

Rieger Bernd (Delft University of Technology, The Netherlands)

Shakhnovich Eugene (Harvard University, Cambridge, USA)

Shechtman Yoav (Technion University, Haifa, Israel)

Smit Berend (EPFL Lausanne, Switzerland)

Sola Miquel (University of Girona, Spain)

Stanciakova Katarina (Utrecht University, The Netherlands)

Taylor Annette (University of Sheffield, UK)

Van Speybroeck Veronique (University of Ghent, Belgium)

Walther Andreas (University of Freiburg, Germany)

Weckhuysen Bert (Utrecht University, The Netherlands)

Wüthrich Kurt (Scripps Research, La Jolla, CA, USA & ETH Zurich, Switzerland)

Yeomans Julia (Oxford University, UK)

# AUDITORS

The Conference was also attended by auditors from various Belgian universities and the Solvay Company. Auditors play an essential role in the transcription of the discussions into a publishable text. The International Solvay Institutes are grateful to the editorial team and in particular to Professors Anne De Wit (Scientific Secretary of the International Solvay Scientific Committee for Chemistry) and Laurence Rongy for their efficient handling of this difficult task.

Emilie Cauët (ULB)

Gino Baron (VUB)

Benoît Champagne (FUNDP, Namur)

Yannick De Decker (ULB)

Anne De Wit (ULB)

Geneviève Dupont (ULB)

Frank De Proft (VUB)

Gert Desmet (VUB)

Paul Geerlings (VUB)

Jeremy Harvey (KUL)

Alain Jonas (UCL)

Martine Prévost (ULB)

Roberto Lazzaroni (U. Mons)

Bortolo Mognetti (ULB)

Yoann Olivier (U. Namur)

Han Remaut (VUB)

Laurence Rongy (ULB)

Rouslan Efremov (VUB)

# SOLVAY SA AUDITORS

Mathieu Bertin

Antoine Emery

Philippe Marion

Patrick Maestro

With the participation of several Nobel Laureates:

Professor Thomas Cech, 1989 Nobel Laureate,
Professor Ben Feringa, 2016 Nobel Laureate,
Professor Stefan Hell, 2014 Nobel Laureate,
Professor Kurt Wüthrich, 2002 Nobel Laureate.

# 16th SOLVAY PUBLIC LECTURES

OCTOBER 20 | 2019

# FRONTIERS OF CHEMISTRY

The annual Solvay Public Lectures took place on October 20, following the 25th Solvay Conference on Chemistry.

The event, entitled "Frontiers of Chemistry" focused on the spectacular developments that occurred recently in optical and electronic microscopy.

Frontiers are often pushed by new exploration means. This is true in many areas, and particularly so in experimental sciences, which rely on observation and experiment. Many scientific breakthroughs occurred thanks to the development of new investigation tools.

Famous historical examples include the discovery of the moons of Jupiter by Galileo with his spyglass (the ancestor of modern telescopes) or the spectacular increase of astronomical knowledge made possible by radio astronomy, ranging from the discovery of quasars to the first observation of the cosmic microwave background radiation.

Equally spectacular, but more recent and in the microscopic world, are the remarkable breakthroughs in optical and electronic microscopy to which the lecturers of the public event actively contributed. These original investigation techniques are Nobel-winning discoveries that revolutionized microbiology by enabling scientists to see, track or monitor things that they could not see before: quoting the Nobel foundation,

> "Scientists can monitor the interplay between individual molecules inside cells; they can observe disease-related proteins aggregate, they can track cell division at the nanolevel and they can portray biomolecules at atomic resolution. These tools have revealed numerous astonishing structures of life's molecular machinery."
>
> *from the Nobel Foundation web site, https://www.nobelprize.org/, Nobel Prize in Chemistry 2017*

*First row: the Solvay family, Mr Yvon Englert, Rector of the ULB, Mr Oberdan Léo, Vice-rector Research (ULB), Mr Ben Craps, Dean of the Faculty of Sciences (VUB) and the representatives of the Solvay Group : Mr Nicolas Boël, chairman of the Board of Directors and Mr Nicolas Cudré-Mauroux, Group General Manager, Research and Innovation.*

These subjects were explained in extremely inspiring and fascinating lectures, given by two scientists who are at the forefront of research in this area.

The lectures were followed by a panel discussion, which addressed questions raised by the public on the future of chemistry.

As usual, the event attracted a great attendance. The International Solvay Institutes are extremely grateful to the two lecturers as well as to the panel members who made this event a great success.

## A TRADITION THAT GOES BACK TO 2005

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 Solvay Group, 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 high attendance of the annual public event provides great satisfaction and encouragement.

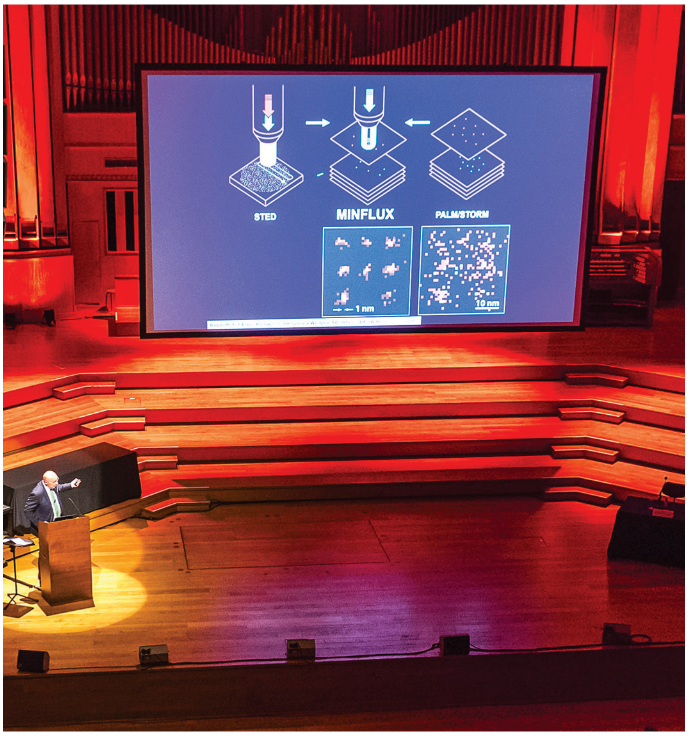
## PROGRAMME

Moderator: Prof. Franklin Lambert (VUB & International Solvay Institutes)

| | |
|---|---|
| 15:00 – 15:05 | Opening by Prof. Marc Henneaux (ULB & International Solvay Institutes) |
| 15:05 – 15:30 | Solvay Awards ceremony |
| 15:30 – 16:15 | "Optical microscopy: the resolution revolution" by Prof. Stefan Hell (Max Planck Institute, Göttingen, Germany) |
| 16:15 – 16:20 | Question session |
| 16:20 – 17:05 | "To get to know biological molecules, freeze them and photograph them!" by Prof. Eva Nogales (UC Berkeley, USA) |
| 17:05 – 17:10 | Question session |
| 17:10 – 17:55 | Panel discussion chaired by Prof. Bert Weckhuysen (Utrecht University, The Netherlands) and with the participation of Profs. Stefan Hell, Eva Nogales, Veronique Van Speybroeck (Ghent University), Julia Yeomans (Cambridge University) |
| 17:55 – 18:00 | Closing |
| 18:00 – 18:30 | Reception |

# LECTURERS

The two lecturers are outstanding world leaders in their fields.


Professor Stefan Hell is a German physicist. He began his studies at the Heidelberg University in 1981, where he received his doctorate in physics in 1990. In 2002, he became a director of the Max Planck Institute for Biophysical Chemistry in Göttingen and he established the department of Nanobiophotonics.

He revolutionized the field of optical microscopy by inventing new methods that substantially improve the resolving power of the fluorescence microscope.

Among other distinctions, he received the Nobel Prize in Chemistry in 2014 "for the development of super-resolved fluorescence microscopy" (Nobel citation), together with Eric Betzig and William Moerner.

Professor Eva Nogales obtained her B.S. degree in physics from the Autonomous University of Madrid in 1988. She later earned her Ph.D. from the University of Keele in 1992. She is head of the Division of Biochemistry, Biophysics and Structural Biology of the Department of Molecular and Cell Biology at the University of California, Berkeley and a Howard Hughes Medical Institute investigator.

She is a leader in electron microscopy, where she combines various complementary techniques (cryogenic electron microscopy, computational image analysis and biochemical assays) to gain insights into the structure and functions of biological complexes and molecular machines.

She received numerous awards for her pioneering work. She has been elected to the US National Academy of Sciences and to the American Academy of Arts and Science.

## PANEL MEMBERS

Prof. Weckhuysen received his master degree in chemical and agricultural engineering with greatest distinction from Leuven University (Belgium) in 1991. After obtaining his PhD degree from Leuven University with honours (highest degree) in 1995, he has worked as a postdoctoral fellow at Lehigh University (USA) and at Texas A&M University (USA). He is since October 2000 Full Professor Inorganic Chemistry and Catalysis at Utrecht University. Prof. Weckhuysen has been appointed as the first Distinguished Professor of the Faculty of Science at Utrecht University as of September 2012. In January 2018 he has been promoted to Distinguished University Professor at Utrecht University. He has received several research awards, including the 2013 Spinoza Award of the Netherlands Organization for Scientific Research.

Prof. Nogales is a Professor of Biochemistry, Biophysics and Structural Biology, and a Howard Hughes Investigator. The Nogales lab is dedicated to gaining mechanistic insight into crucial molecular processes in the life of the eukaryotic cell. Their two main research themes are the dynamic self-assembly of cytoskeleton during its essential functions in cell division, and the molecular machines governing the regulation of gene expression, specially at the transcriptional level. The unifying principle in their work is the emphasis on studying macromolecular assemblies as whole units of molecular function by direct visualization of their architecture, functional states and regulatory interactions. With this overall aim in mind they use electron microscopy and image analysis, complemented with biochemical and biophysical assays, towards a molecular understanding of their systems of interest.

Prof. Hell's group is developing light microscopes with a spatial resolution down to a few nanometers, particularly, but not exclusively, for imaging cells and tissue of a living organism. Prominent methods include STED and RESOLFT microscopy as well as concepts based on stochastic single-molecule switching such as GSDIM microscopy. To surpass the diffraction barrier, all these methods utilize a reversible transition or switch of fluorescent labels between a bright and a dark state. In combination with 4Pi microscopy, which is another concept developed by this group that uses two opposing lenses, the resolution can be increased in all spatial dimensions down to the nanometer scale. Since these superresolution concepts fundamentally rely on transitions between molecular states, novel labels are required that can be optically prepared in at least two different states. Consequently, the group also pioneers the chemical synthesis and application of new labeling methods and techniques to improve the performance of the labels' switching behavior to separate close-by molecules.

Prof. Van Speybroeck is full professor at the Ghent University within the Faculty of Engineering and Architecture, since October 2012. She also holds a position as Research Professor at the Ghent University since October 2007. She graduated as engineer in physics at the Ghent University in 1997 and obtained her PhD in 2001. She was co-founder in 1997 of the Center for Molecular Modeling (CMM), which is now composed of about 40 researchers. After her PhD she received a postdoctoral fellowship from the National Fund for Scientific Research Flanders and had the possibility to travel to various foreign institutes.

She built up a large expertise in first principle kinetics in nanoporous materials in the frame of an ERC starting grant, awarded in 2010. Her current research interests focus on first principle molecular dynamics simulations of complex chemical transformation in nanoporous materials, for which she received an ERC Consolidator grant in 2015.

Prof. Yeomans obtained her MA in Physics and DPhil in Theoretical Physics from the University of Oxford. She spent two years as a post doc at Cornell University, USA and then returned to the UK, to a Lectureship at the University of Southampton. Shortly thereafter she joined the Rudolf Peierls Centre for Theoretical Physics at Oxford. She is currently Professor of Physics at Oxford, a member of the Oxford Centre for Soft and Biological Matter, and Pauline Chan Fellow, St Hilda's College. She was also awarded the EPJE Pierre Gilles De Gennes Lecture Prize, for her contribution to the study of the dynamical behaviour of complex and active liquids in confined geometries. In 2012, Prof. Yeomans was awarded a European Research Council Advanced Research Grant for her research proposal "Microflow in complex environments". She was elected a Fellow of the Royal Society (FRS) in 2013.

# SOLVAY AWARDS:
## A POOL OF SCIENTIFIC TALENTS FOR INNOVATION



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 Solvay Awards Ceremony. These Solvay awards are given by the Solvay Company.

The Solvay Awards rewarded 8 PhD students and bright minds from the Faculty of Sciences and the Faculty of Engineering of both Université Libre de Bruxelles (ULB) and Vrije Universiteit Brussel (VUB), renewing Solvay's commitment to open innovation to help address shared future challenges with the best of scientific advancement.

The Solvay Awards ceremony celebrates the talent and expertise of the laureates, their specialties, and distinguished academic career in chemistry or physics presenting ground-breaking research.

The selection done by the Solvay Awards Jury takes into account work submitted for evaluation both for basic or applied nature, focusing on one of the following fields:

- the investigation and understanding of matter (structure, properties, transformation, chemical reactivity, material science)
- the study of the mechanisms and chemistry of life
- new production technologies
- new resources, energy storage and generation
- environmental sciences and sustainable development


# THE 2018 LAUREATES

BAUMAN, David
(ULB)

MONTERO CARRERO, Marina
(VUB)

HINDERDAEL, Michaël
(VUB)

SIMONINI, Alessia
(ULB)

LAMBEETS, Sten
(ULB)

VAN DER POORTEN, Olivier
(VUB)

MENDEZ, Alfonso Miguel
(ULB)
*represented by his promotor, Professor Buchlin*

VAN LAETHEM, Dries
(VUB)

# INTERNATIONAL SOLVAY CHAIRS

# INTERNATIONAL SOLVAY CHAIRS

The International Solvay Chair programme enables the Institutes to invite to Brussels eminent scientists 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 program in chemistry was launched in 2008 thanks to a generous grant from the Solvay Company, which the Institutes gratefully acknowledge.

## 2019 INTERNATIONAL SOLVAY CHAIR IN CHEMISTRY

**Professor Gernot Frenking** I Philipps-Universität Marburg, Germany

The twelfth International Chair in Chemistry was held by Professor Gernot Frenking from the Philipps-Universität Marburg (Germany).

Professor Frenking is a world-leading theoretical chemist. He is the author of more than 715 papers in international scientific journals. His research interests are very diverse and include the bonding analysis of molecules and compounds with unusual chemical bonds, dative bonding in main group chemistry and the detailed theoretical scrutiny of reaction mechanisms.

His splendid opening lecture "The Chemical Bond", given on March 12, provided a fascinating review of the subject. It was attended by many students and researchers from the ULB, the VUB and other Belgian universities.

During his stay in Brussels, Professor Frenking was hosted in the group of Professors Frank De Proft and Paul Geerlings, with whom fruitful collaborations were initiated.

The Institutes thank both of them for their very useful help in organizing the chair.

Professor Frenking spent two months in Brussels, one in the Spring and one in the Fall.

After his chemistry studies at the Rhenish-Westphalian Technical University Aachen, Prof. Frenking was a research student in Kyoto (Japan) with the late Prof. Kenichi Fukui, who received the 1981 Nobel prize in Chemistry, together with Roald Hoffmann. From 1976 to 1979, he did his PhD studies at the Technical University Berlin, performing theoretical work on phosphorus(III) compounds. He finished his habilitation, also in Berlin, in 1984. After one year as Visiting Scientist at the University of California, Berkeley, USA, working with Henry F. Schaefer III, he joined the Stanford Research Institute, Menlo Park, CA, USA, as staff scientist in 1985.

In 1990, Gernot Frenking became Professor for Computational Chemistry at the Philipps-Universität Marburg, Germany, and in 1998, was named Full Professor for Theoretical Chemistry. He remained in Marburg until his retirement in 2014. He continued his research there as Professor Emeritus and also works as Ikerbasque Visiting Research Professor at the Donostia International Physics Center in San Sebastian, Spain. In addition, he received a honorary Professorship of Nanjing Tech University in China.

Among other honors, Professor Frenking has received the Elhuyar-Goldschmidt Prize by the Spanish Royal Society of Chemistry in 2007, the Schrödinger Medal of the WATOC (World Association of Theoretical and Computational Chemists) in 2009, the Hofman Distinguished Lecture in 2010 at Imperial College, London, Lise-Meitner Lecturer and The Hebrew University of Jerusalem, Israel in 2011 and he was awarded the Hans Hellman Research Professorship Award of the University of Marburg in 2012. He serves as Editor of the Journal of Computational Chemistry and he is, among others, member of the Editorial board of Theoretical Chemistry Accounts and the International Journal of Quantum Chemistry.

**Inaugural lecture** | 12 March 2019

## THE CHEMICAL BOND

*The historical development of the concept of the chemical bond and the physical understanding of chemical bonding is not only a fascinating chapter of chemistry as a scientific discipline. It also reflects human attempts to understand the material world and the process of conquering and changing matter at one's own discretion. It was not until 1927 that physical laws were available, which provided a basis for an understanding of the nature of the chemical bond in terms of fundamental physical forces. But even before this time heuristic bonding models had been proposed which had proved very useful as ordering principles and guidance for new experiments. The remarkable success of these models contributed to the booming development of the chemical industry as a very important part of wealth and economy. Chemistry can be seen as an example of significant progress being made in a scientific discipline without its fundamental basis being known.*

*The physical understanding of chemical bonding, introduced in 1927, was based on the newly developed quantum theory of Werner Heisenberg and Erwin Schrödinger. Following their work, Walter Heitler and Fritz London applied quantum theory to the nature of the chemical bond. They showed for the first time that the strong interatomic interactions leading to a chemical bond can be explained by fundamental physical forces. But the complicated mathematical formulation, which appeared intractable at a time when computers were not available, and the enormous difficulties in grasping the meaning of a quantum theoretical description of chemical bonding with a model accessible to the human mind were great obstacles to make quantum chemistry a valuable discipline competing with experiment.*

*In my lecture I will outline the historical development of the concept of the chemical bond and the physical understanding of chemical bonding, which is an ongoing topic of controversial – and thus fruitful – discussion.*

**Lecture 1** I 20 March 2019

## TRAVELLING IN VALENCE SPACE

*Before the advent of quantum chemistry in 1927, heuristic rules were suggested which are still remarkably useful to explain and predict molecular structures and reactivities. Prominent examples are the electron-pair model for the chemical bond introduced in 1916 by Gilbert Lewis and the octet and 18- and 32-electron rules by Irving Langmuir in 1921. In my lecture I will discuss the quantum chemical underpinning of the rules and recent developments that transcend the limits of conventional understanding of the models.*

**Lecture 2** I 29 March 2019

## DATIVE BONDING IN MAIN GROUP COMPOUNDS

*The lecture focuses on chemical bonding in one, two- and three-centre complexes of main-group atoms E, which is described in terms of dative bonds. It is shown that the bonding model of donor-acceptor interactions provides insight and understanding for unusual geometries. It served in recent years as useful guideline for the explanation of the bonding situation and the successful prediction of novel molecules. The field of experimentally known complexes which are shown below has greatly increased in the recent past with the support of quantum chemical calculations.*

**Lecture 3** I 5 November 2019

## CONJUGATION, HYPERCONJUGATION AND AROMATICITY

*This lecture focusses on important models for chemical bonding, which are ubiquitously used for the description of molecular structures and reactivities, often without solid fundament but merely used as heuristic pseudo explanation. I will emphasize the difference between a bonding model and the physical mechanism of chemical bond formation. The unobservable concepts of conjugation, hyperconjugation and aromaticity can quantitatively be derived from the terms of an energy decomposition analysis (EDA) which correlate quite well with experimental observations. I will also make some critical remarks concerning the frequently made correlation between magnetic current and aromaticity.*

**Lecture 4** I 12 November 2019

## CHEMICAL BONDS IN DIATOMIC MOLECULES

*I will discuss the nature of the chemical bond in some elementary diatomic molecules using charge and energy decomposition methods. Particular attention is paid on the chemical bond in CO and the shortest known bond between any two atomic species heavier than hydrogen and helium.*

# 2018 INTERNATIONAL SOLVAY CHAIR IN CHEMISTRY

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

The last lectures of Professor Feringa, who held the 2018 Solvay Chair in Chemistry, were given in April of 2019.

**Lecture 2** I 9 April 2019

## CATALYTIC ASYMMETRIC CATALYSIS

*The challenge to develop the fully catalytic sustainable organic synthesis of the future sets the stage for a new era in asymmetric catalysis. Besides high levels of activity and selectivity, practicality of the new catalytic methodologies is a key parameter. The design of catalytic toolkits and tandem catalytic conversions are other important aspects. In this lecture new catalytic systems based on monodentate phosphoramidite ligands with a focus on C-C bond formation will be presented. The enantioselective transformations include catalytic conjugate addition reactions of organozinc and Grignard reagents and allylic alkylation of organolithium reagents with absolute levels of stereocontrol. Furthermore, approaches towards dynamic control of chirality and surpamolecular systems are discussed. The synthetic methodology will be illustrated in the total synthesis of structures demanding remote acyclic stereocontrol.*

**Lecture 3** I 9 April 2019

## PHOTORESPONSIVE BIOMOLECULAR SYSTEMS

*The biomolecular machinery that sustains life is a great source of inspiration to design dynamic and responsive functional molecular systems. Can we make smart drugs that can be delivered and activated exclusively at the disease spot? In this lecture I will discuss different approaches currently taken to address some of basic challenges associated with dynamic molecular systems. In particular the use of light offers bright and unconventional opportunities. Light is a non-invasive signal and can be delivered with high precision in space and time. The principles and opportunities of photo pharmacology will be discussed. Light allows the on-off switching of the activity of a therapeutic agent, as will be illustrated for antibiotics and antitumor drugs. New synthetic methodology towards tracers for molecular imaging is also shown. Other possibilities include potential systems for drug delivery based on selfassembled and light-responsive nano-tubes and vesicles. In the final part of this voyage fundamental principles of autonomous propelling systems are presented that might ultimately form the basis for the roving sensors.*

**Lecture 4** I 11 April 2019

## MOLECULAR SWITCHES AND MOTORS

*The fascinating molecular motors and machines that sustain life offer a great source of inspiration to the molecular explorer at the nanoscale. Among the major challenges ahead in the design of complex artificial molecular systems is the control over dynamic functions and responsive far-from-equilibrium behaviour. Chemical systems ultimately require integration of structure, organization and function of multi-component dynamic molecular assemblies at different hierarchical levels. A major goal is to achieve and exploit translational and rotary motion. In this presentation the focus is on the dynamics of functional molecular systems as well as triggering and assembly processes. We design switches and motors in which molecular motion is coupled to specific functions. Responsive behaviour will be illustrated in self-assembly, information systems, supramolecular and polymer materials, responsive surface and artificial muscles. The design, synthesis and functioning of rotary molecular motors and machines will be presented with a prospect toward future dynamic molecular systems.*

# 2019 INTERNATIONAL SOLVAY CHAIR IN PHYSICS

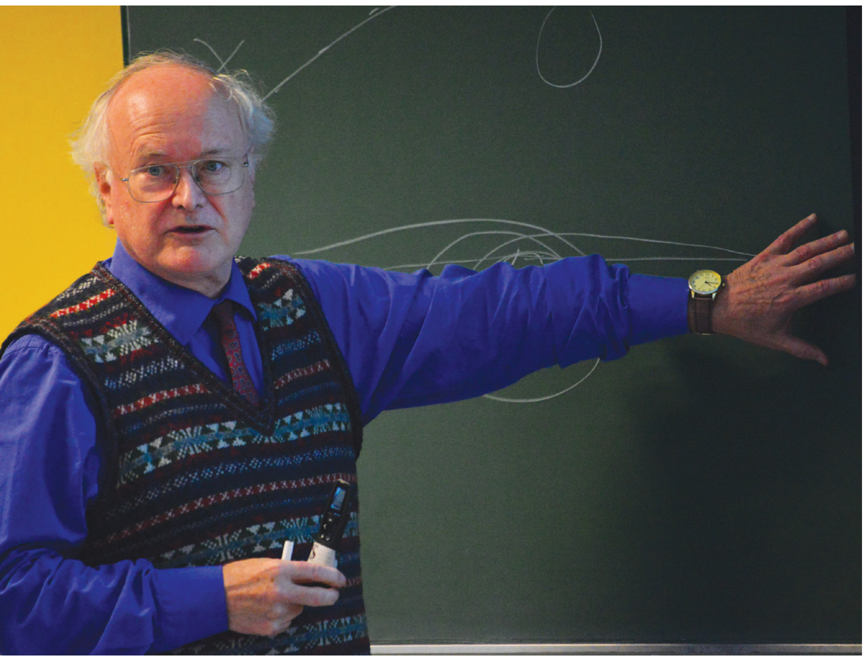
**Professor Gary Gibbons** I DAMTP, University of Cambridge, UK

The 2019 International Jacques Solvay Chair in Physics was held by Professor Gary Gibbons from the University of Cambridge (UK).

Gary Gibbons is a world-leader in gravitation theory. He has made deep and inspiring contributions to quantum gravity and black holes, where he pioneered many key developments, including the use of Euclidean methods. The number of phenomena or structures that bear his name is a testimony of his profound and long-lasting influence. Let us only mention the Gibbons-Hawking effect attributing on general grounds a temperature to event horizons.

«Space, Time and Symmetry» is a profound question of physics. It was the subject of Professor Gibbons's inaugural lecture, which he gave on September 24, 2019. The inaugural lecture was followed by a course of lectures on "Applications of non-relativistic symmetries and non-relativistic spacetimes."

*Madame Solvay de la Hulpe, Professor Françoise Englert, 2013 Nobel Laureate and Mrs Marina Solvay.*



Professor Gibbons is a true "Cambridgian". He became a research student in Cambridge in 1969 and was the first to get a PhD degree under the direction of Stephen Hawking, in 1973.

Apart from a postdoctoral stay at the Max Planck Institute in Munich in the 1970s, and extended invitations at prestigious institutions such as the Institute for theoretical physics in Santa Barbara, the Ecole Normale Supérieure in Paris, the Yukawa Institute in Kyoto, MIT and many others, he has remained in Cambridge throughout his career. He became a full professor in 1997 and a Fellow of Trinity College, Cambridge in 2002.

Professor Gibbons was elected a Fellow of the Royal Society (FRS) in 1999. His nomination provides a precise presentation of his work:

"Distinguished for his contributions to General Relativity and the Quantum Theory of Gravity. He played a leading role in the development of the Euclidean approach to quantum gravity and showed how it could be used to understand the thermal character of black holes and inflating universes. This revealed a deep and unexpected relationship between gravitation and thermodynamics. [As part of the Euclidean quantum gravity programme, he discovered many of the known gravitational instantons and classified their properties. In the more conventional Lorentzian approach to gravity, he has studied the behaviour of solitons in gauge theories and General Relativity and has shown how supersymmetry leads to Bogomolny inequalities on the masses and charges. More recently he has been investigating the role of topology in gravity and has obtained important restrictions on how the topology of spacetime can change.] He is recognised worldwide as a leader in the field."

**Inaugural Lecture** I 24 September 2019

## SPACE, TIME AND SYMMETRY

*After one hundred years of tests and observations, Einstein's Theory of General Relativity remains our most fundamental account of the nature of gravity. Together with the Standard Model of Particle Physics, it is the basis for all of our current understanding of the workings of the physical world from microscopic to cosmological scales.*

*In this lecture, directed to a general audience, I will describe the historical process whereby starting from the achievements of Copernicus, Galileo and Newton, Einstein was drawn to attribute physical reality to a unification of space and time called Spacetime, and ascribe the force of gravity to the curvature of spacetime. It will be explained that the issue ultimately boils down to the symmetry, that is invariance, of all physical laws, such as those governing the propagation of light under changes of reference frame.*

*In doing so, there results a theory which incorporates in a mathematically consistent fashion some of the most daring and imaginative insights and speculations on light bending, black holes, non-Euclidean geometry, expanding universes and travelling back in time, and which continues to fascinate to this day.*

**Course of Lectures**

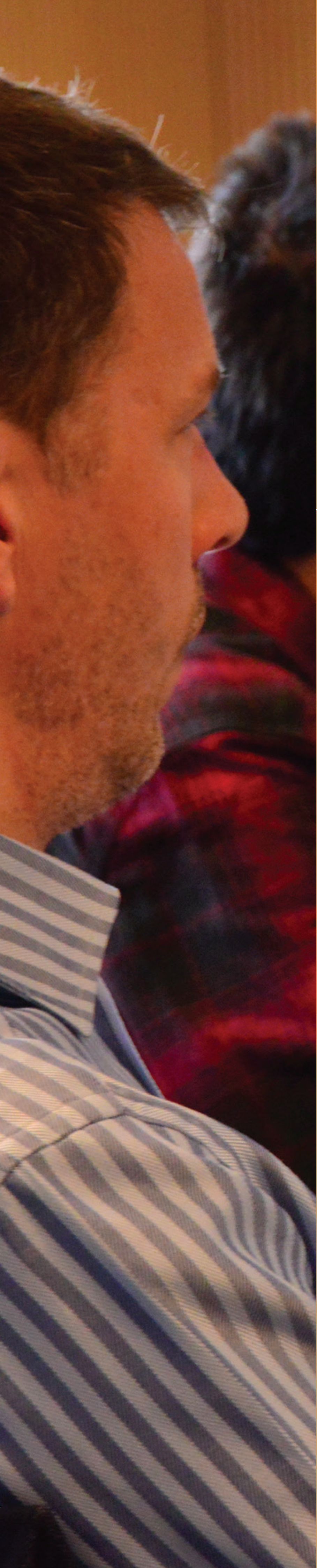
## APPLICATIONS OF NON-RELATIVISTIC SYMMETRIES AND NON-RELATIVISTIC SPACETIMES: A SURVEY

**Lecture 1** I 25 September 2019

**Lecture 2** I 26 September 2019

**Lecture 3** I 30 September 2019

**Lecture 4** I 2 October 2019



# WORKSHOPS AND SCHOOLS

## ORGANIZED BY THE INSTITUTES

# CONTENTS

WORKSHOP ON

# “QUANTUM SIMULATION 2019”

**18 - 20 FEBRUARY 2019**


Quantum simulation denotes the approach by which controllable many-body quantum systems are designed and analysed in view of revealing complex and intriguing quantum phenomena. This fast growing field of research gathers a huge community of scientists specialized in various branches of quantum physics, including condensed-matter physics, atomic and molecular physics, quantum optics, quantum information and high-energy physics. The workshop assembled a unique group of leading experts, who significantly contributed to the development of quantum simulation, and/or closely-related topics, in the recent years.

The subjects discussed at the workshop included:

- Cold atoms in optical lattices, Rydberg atoms and cold molecules
- Physics of trapped ions
- Hybrid quantum systems
- Quantum fluids of light: Photonic crystals, polaritons, and cavity quantum electrodynamics
- Superconducting circuits and quantum-dot-based spin qubits
- Quantum Hall physics, topological states of matter and strongly-correlated systems
- Quantum many-body dynamics, non-equilibrium dynamics, many-body localization
- Quantum simulation of lattice gauge theories

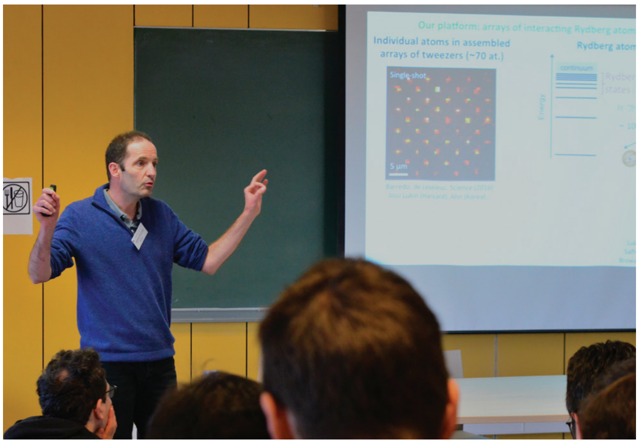
## SCIENTIFIC COMMITTEE

Ehud Altman (Weizmann I., Israel)
Rainer Blatt (U. of Innsbruck, Austria)
Immanuel Bloch (MPQ, Garching, Germany)
Iacopo Carusotto (U. of Trento, Italy)
Ignacio Cirac (MPQ, Garching, Germany)
Jean Dalibard (ENS, Paris, France)
Maciej Lewenstein (ICFO, Barcelona, Spain)
Jean-Michel Raimond (UPMC, Paris, France)
Uwe-Jens Wiese (U. of Bern, Switzerland)

## ORGANIZING COMMITTEE

Nathan Goldman (ULB, Brussels, Belgium)
Ben Craps (VUB, Brussels, Belgium)
Wojciech De Roeck (KU Leuven, Belgium)
Jacques Tempere (U. of Antwerp, Belgium)
Frank Verstraete (Ghent U., Belgium)
Peter Zoller (U. of Innsbruck, Austria)

## SPEAKERS




Rainer Blatt (U. of Innsbruck, Austria)
Immanuel Bloch (MPQ, Garching, Germany)
Jacqueline Bloch (C2N/CNRS, Marcoussis, France)
Antoine Browaeys (Institut d'Optique, Palaiseau, France)
Peter Brown (Princeton U., USA)
Ignacio Cirac (MPQ, Garching, Germany)
Nigel R. Cooper (Cambridge U., UK)
Jean Dalibard (ENS, Paris, France)
Markus Greiner (Harvard U., Cambridge, USA)

Duncan Haldane (Princeton U., USA)
Maciej Lewenstein (ICFO, Barcelona, Spain)
Mikhael Lukin (Harvard U., Cambridge, USA)
Christopher Monroe (U. of Maryland, USA)
Christine Muschik (U. of Waterloo, Ontario, Canada)
Markus Oberthaler (Heidelberg U., Germany)
Anatoli Polkovnikov (Boston U., USA)
Steven H. Simon (U. of Oxford, UK)
Jonathan Simon (U. of Chicago, USA)
Ian B. Spielman (NIST, Gaithersburg, USA)
Alexander Szameit (Rostock U., Germany)
Dam Thanh Son (U. of Chicago, USA)
Lieven Vandersypen (TU Delft, The Netherlands)
Benoit Vermersch (U. of Innsbruck, Austria)
Norman Yao (UC Berkeley, USA)

## PROGRAMME

### Monday 18 February 2019

Opening by Marc Henneaux

| | |
|---|---|
| Ignacio Cirac | *Quantum optics in structured baths* |
| Benoit Vermersch | *Probing entanglement and scrambling via random measurements* |
| Rainer Blatt | *Quantum simulation with trapped Ca+ Ions* |
| Christopher Monroe | *Quantum Circuits and Simulation with Individual Atoms* |
| Dam Thanh Son | *Physics of composite fermions in the fractional quantum Hall effect* |
| Duncan Haldane | *Geometry of flux attachment in the FQHE* |
| Steven H. Simon | *Interesting Things about Fractional Quantum Hall Edges* |
| Nigel R. Cooper | *Topological phases of matter out of equilibrium* |
| Norman Yao | *Non-equilibrium phases of quantum matter* |


### Tuesday 19 February 2019

| | |
|---|---|
| Immanuel Bloch | *Probing and Controlling Quantum Matter at the Single Atom Level* |
| Markus Greiner | *A Microscopic View on Quantum Matter: From Fermi-Hubbard Physics to Many-Body Localization* |
| Mikhael Lukin | *Exploring quantum dynamics with Rydberg atom arrays* |
| Antoine Browaeys | *Many body physics with individual Rydberg atoms* |
| Peter Brown | *Probing transport and spectral properties of Fermi-Hubbard systems with a quantum gas microscope* |
| Jean Dalibard | *Scale invariance and breathers in a 2D quantum fluid* |
| Alexander Szameit | *Non-hermitian topological photonics* |
| Jonathan Simon | *Photonic Matter: From Mott Insulators, Landau Levels, and Floquet Polaritons* |

### Wednesday 20 February 2019

| | |
|---|---|
| Christine Muschik | *Quantum simulation of problems from high energy physics* |
| Markus Oberthaler | *Universal time dynamics: connection between quark gluon plasma and ultracold gases* |
| Ian B. Spielman | *Topology of the Rashba model (Experiment) and quantum gases with weak measurement and classical feedback (Theory)* |
| Maciej Lewenstein | *Detection of topological order with quantum simulators* |
| Anatoli Polkovnikov | *Quantum simulations of interacting systems using phase space methods* |
| Lieven Vandersypen | *Simulating magnetism using semiconductor quantum dot arrays* |
| Jacqueline Bloch | *Toward many body physics with light in arrays of semiconductor cavities* |
| Concluding remarks | |

WORKSHOP ON

# THE DARK SIDE OF BLACK HOLES

3 - 5 APRIL 2019


It has been long hypothesized that there might be a close connection between black holes (BH) and the dark matter of the Universe (DM). That connection potentially goes both ways. For one, BH could have formed already in the Early Universe by gravitational collapse of density fluctuations. Such primordial black holes (PBH) could have survived till present epoch and serve an attractive DM candidate that does not require a new stable particle – a particle long sought for by direct and indirect DM experiments and not (yet) detected. Conversely, many particle DM models (WIMPs or axion-like particles) exhibit new mechanisms of BH formation, allow for compact star-like objects resembling BH or show other specific effects that make BH observations good probes for these models. The interest in such possibilities was recently spinned up by the detection of gravitational waves from merging BHs and neutron stars, observations that open new ways to study BH and similar compact objects. In this Solvay workshop, the most recent advances in this hot and timely topic were discussed, focusing on the interplay between black holes and other compact objects and the dark matter problem.

## SCIENTIFIC & ORGANIZING COMMITTEE

Sébastien Clesse (UNamur, Belgium)
Ben Craps (VUB, Brussels, Belgium)
Thomas Hertog (KU Leuven, Belgium)
Christophe Ringeval (UCL, Louvain, Belgium)
Laura Lopez Honorez (ULB, Brussels, Belgium)
Alexander Sevrin (VUB, Brussels, Belgium)
Petr Tinyakov (ULB, Brussels, Belgium)
Michel Tytgat (ULB, Brussels, Belgium)

## SPEAKERS

Yacine Ali-Haïmoud (NYU, New York, USA)
Joseph Bramante (Queen's U. Kingston, Ontario, Canada)
Christian Byrnes (U. of Sussex, Brighton, UK)
Francesca Calore (LAPTh, Annecy-le-Vieux, France)
Vitor Cardoso (ISR-Lisboa, Portgual)
Bernard Carr (Queen Mary, U. of London, UK)
Alexander Dolgov (INFN Sezione di Ferrara, Italy)
Sergei Dubovsky (NYU, New York, USA)
Juan-García Bellido (UAM, Madrid, Spain)
Anne Green (Nottingham U., UK)
Alexander Kashlinsky (NASA, Greenbelt, USA)
Joachim Kopp (Johannes Gutenberg U. Mainz, Germany)
Chris Kouvaris (U. of Southern Denmark, Odense)
Paolo Pani (Sapienza U., Roma, Italy)
Martti Raidal (KBFI, Tallinn, Estonia)
Teruaki Suyama (Tokyo Institute of Technology, Japan)
Igor Tkachev (INR RAS, Moscow, Russia)
Jo van den Brand (Nikhef & VU U., Amsterdam, The Netherlands)
Licia Verde (ICC, Barcelona, Spain)
Hai Bo Yu (UCR, California, USA)

## PROGRAMME

### Wednesday 3 April 2019

Welcome address by Marc Henneaux, Director of the Solvay Institutes

| | |
|---|---|
| Bernard Carr | *Microscopic and macroscopic black holes: linking the light and the dark* |
| Sergei Dubovsky | *Looking for axions with astrophysical black holes* |
| Jo van den Brand | *Gravitational wave results from LIGO and Virgo* |
| Licia Verde | *Primordial black holes: the cosmology connection* |
| Teruaki Suyama | *Merger rate of primordial black hole binaries* |
| Hai Bo Yu | *Self-interacting Dark Matter* |
| Igor Tkachev | *Axion stars: formation and collapse* |

### Thursday 4 April 2019

| | |
|---|---|
| Juan-García Bellido | *Signatures of Primordial Black Holes as Dark Matter* |
| Yacine Ali-Haïmoud | *PBH as dark matter* |
| Francesca Calore | *Constraining Primordial Black Holes with High-energy Astrophysics* |
| Alexander Kashlinsky | *The Bright Side of Black Holes: dark matter, primordial black holes and the cosmic infrared background* |
| Vitor Cardoso | *The bright side of Black Holes* |
| Paolo Pani | *Black-hole superradiance: probing ultralight bosons with compact objects and gravitational waves* |
| Martti Raidal | *Constraints on PBH binaries from N-body simulations* |
| Christian Byrnes | *Constraining cosmology with primordial black holes* |

### Friday 5 April 2019

| | |
|---|---|
| Chris Kouvaris | *Dark stars, Dark Matter and Black Holes* |
| Joseph Bramante | *Explosive Dark Matter Production of Heavy Elements in Compact Stars* |
| Anne Green | *Microlensing constraints on Primordial Black Hole dark matter* |
| Joachim Kopp | *Femtolensing Constraints on Primordial Black Holes* |
| Alexander Dolgov | *New data about massive black holes and possible interpretation* |

# MIMI FEST:

## 65 YEARS OF INDEFECTIBLE COMMITMENT AND DEDICATED SUPPORT TO THE SOLVAY INSTITUTES

## 8 JULY 2019

### THE SOLVAY FAMILY HAS BEEN SUPPORTING FUNDAMENTAL SCIENCE FOR MORE THAN A CENTURY.

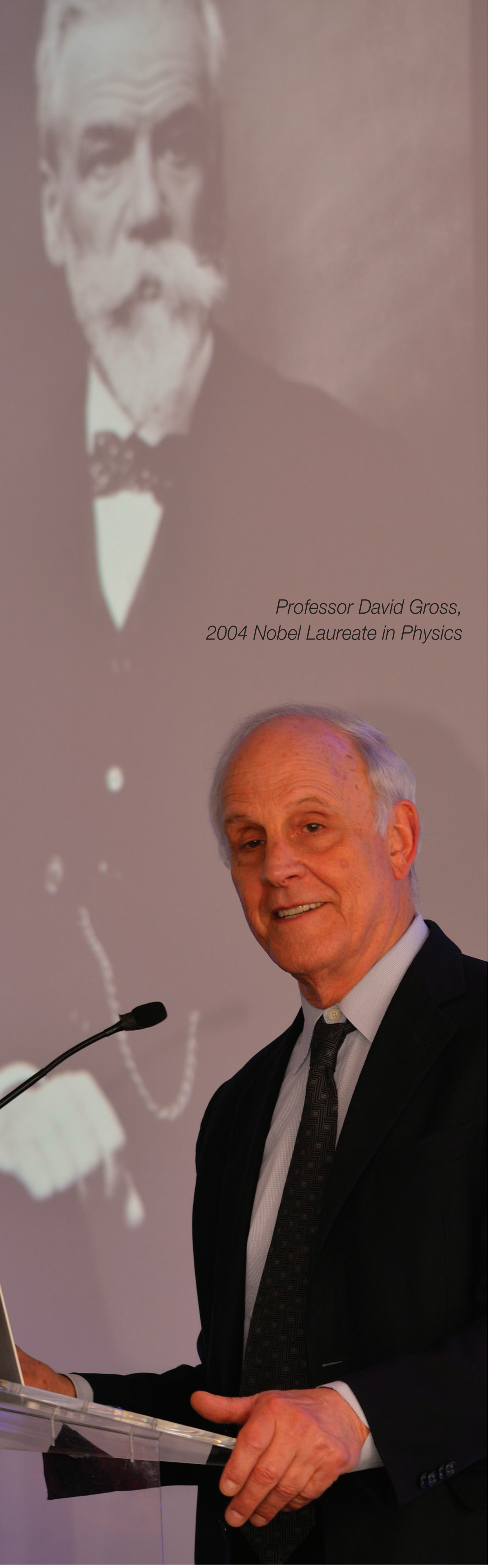
The benevolent involvement of Mrs. Solvay ("Mimi") with the Solvay Institutes started in 1954 on the occasion of the 10th Solvay Conference on Physics, "Les électrons dans les métaux". Since then, for 65 years, i.e., for more than half the existence of the Solvay Institutes, Mrs. Solvay has carried the torch of the philanthropy of the Solvay family with unfailing commitment. This is a unique example of long-lasting support to curiosity-driven research. This generosity carries a distinctive touch that makes it very special, without which the International Solvay Institutes would not be what they are. The participants in the Solvay Conferences, who all keep a vivid memory of the charming receptions at the Long Fonds, will certainly agree with this statement!

On July 8, the International Solvay Institutes celebrated Mrs. Solvay's exceptional commitment and support by organizing a one-day fest in her honor.

The event gathered in a family atmosphere scientists and friends of the Institutes. The history of the Solvay Conferences and of their impact on the development of science were recalled, the similarities between Ernest Solvay and Alfred Nobel were covered, and the figures of Robert Oppenheimer and of Stephen Hawking, who came often to the Solvay activities and for whom Mrs. Solvay had a caring appreciation, were also remembered.

The event took place in the House of Ernest Solvay in Brussels.

It was preceded for the international guests by the visit of the "Hotel Solvay", a jewel of "Art Nouveau".



Professor David Gross,
2004 Nobel Laureate in Physics

*The Solvay family and Mr Yvon Englert, rector of the ULB.*

## PROGRAMME

| | |
|---|---|
| 13:00 - 14:30 | Welcome lunch |
| 14:30 - 14:50 | Opening |
| 14:50 - 15:15 | Professor David Gross, 2004 Nobel Laureate: *The Solvay Conferences on Physics* |
| 15:15 - 15:40 | Professor Kurt Wüthrich, 2002 Nobel Laureate: *The Success Story of the Solvay Conferences on Chemistry* |
| 15:40 - 16:05 | Professor Franklin Lambert: *Ernest Solvay and the beginnings of the Solvay Councils* |
| 16:05 - 16:35 | Coffee Break |
| 16:35 - 17:00 | Professor Lars Brink: *Nobel and Solvay* |
| 17:00 - 17:25 | Professor Robbert Dijkgraaf: *Oppenheimer and the Solvay Institutes* |
| 17:25 - 18:00 | Professors Malcolm Perry and Thomas Hertog: *Remembering Stephen Hawking* |
| 18:00 - 18:20 | Jean-Marie Solvay: *65 years of indefectible commitment and dedicated support to the Solvay Institutes* |
| 18:20 - 18:30 | Closing |
| 18:40 | Dinner |

*Professor Marc Henneaux, Director of the Solvay Institutes*

1 Professor Franklin Lambert

2 Professor Lars Brink

3 Professor Kurt Wüthrich, 2002 Nobel Laureate in Chemistry

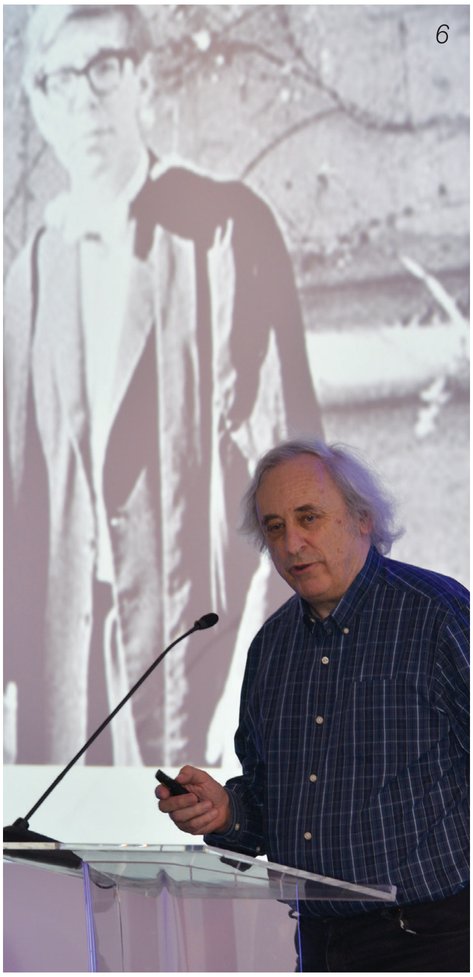
4 Mr Daniel Janssen and Mr Philippe Busquin

5 Mrs Solvay and Professor David Gross, 2004 Nobel Laureate in Physics

6 Professor Malcolm Perry

7 Professor Robbert Dijkgraaf

8 Professor Thomas Hertog

# MODAVE SUMMER SCHOOL

## IN MATHEMATICAL PHYSICS

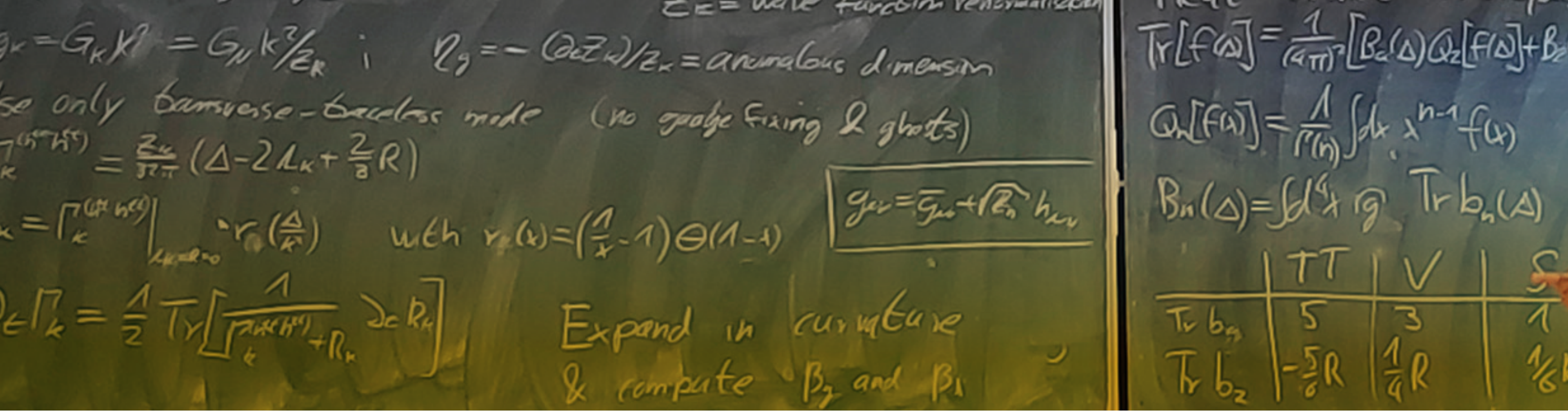
## 8 - 14 SEPTEMBER 2019

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. The lectures cover core subjects that contribute to the backbone knowledge of the participants working in the field of theoretical and mathematical physics, which includes topics in General Relativity, Quantum Field Theory and String Theory.

The year 2019 marked the 15th edition of the school! As for the previous years, the ULB, VUB, KUL and UMONS joined their forces to propose a unique scientific and human experience in the heart of the Belgian countryside.

## ORGANIZING COMMITTEE

Pieter Bomans (KUL)
Martin Bonte (ULB)
Marine De Clerck (VUB)
David De Filippi (UMONS)
Saskia Demulder (VUB)
Sibylle Driezen (VUB)
Adrien Fiorucci (ULB)
Kwinten Fransen (KUL)
Frederik Goelen (KUL)
Yegor Goncharov (UMONS)
Tom Lemmens (KUL)
Vincent Luyten (VUB)
Vincent Min (KUL)
Daniel Naegels (ULB)
Kévin Nguyen (VUB)
Pierluigi Niro (ULB)
Antoine Pasternak (ULB)
Romain Ruzziconi (ULB)
Magnus Tournoy (KUL)
Lucas Traina (UMONS)
Guillaume Valette (ULB)
Jesse van Muiden (KUL)
Quentin Vandermiers (ULB)
Gerben Venken (KUL)



## LECTURES: TOPICS AND SPEAKERS

*Asymptotic Symmetries in Gauge Theories and the BMS Group*
by Romain RUZZICONI (ULB, Brussels)

*In these lectures, we will discuss some general aspects of asymptotic symmetries in gauge theories. We will explain how to impose consistent sets of boundary conditions, and how to compute the asymptotic symmetry parameters. The different procedures to obtain the associated charges will be presented. As an illustration of these concepts, the example of 4d General Relativity in asymptotically flat spacetime will be covered. This will enable us to discuss the different extensions of the Bondi-Metzner-Sachs (BMS) group and their relevance for soft gravitons theorems, memory effects, and black hole information paradox.*

*A bird's eye view on background-independent quantum gravity*
by Philipp HÖHN (University of Vienna)

*We will revisit arguments for why gravity should be quantized in the first place, before developing a wish list of what features a putative theory of quantum gravity should have. For concreteness, we will discuss how this wish list may or may not be fulfilled by attempting to quantize geometric degrees of freedom directly, while respecting key properties of general relativity such as its diffeomorphism symmetry. In contrast to the usual quantization of fields on a fixed spacetime, this calls for a background-independent quantization of spacetime. I will give an overview of canonical and path integral approaches attempting to meet such requirements, such as loop quantum gravity and spin foam models, focusing on their main ideas, achievements and challenges.*

*Topological Field Theory*
by Wolfger PEELAERS (University of Oxford)

*Topological quantum field theory (TQFT) is a vast and rich subject that relates in a profound way physical observables to mathematical quantities. In these lectures, we will define TQFTs both from a physical and a mathematical point of view, formalizing the intuition that only the topology of the underlying manifold matters. In particular, we will introduce Witten's topological twist as a means to obtain so-called Witten-type or cohomological TQFTs, and we will look into Atiyah's axiomatic definition, which for one- and two-dimensional TQFTs provides a particularly intuitive, pictorial representation of their algebraic structure. Further, we will explore some of their applications in both physics and mathematics.*

*Renormalization Group*
by Manuel REICHERT (University of Southern Denmark)

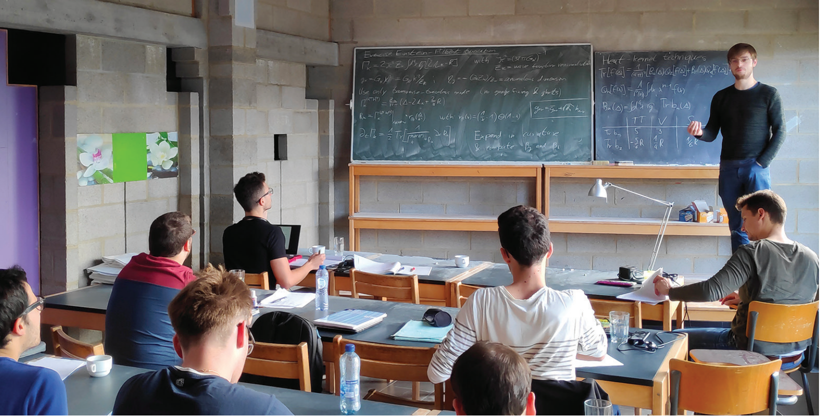
*Non-perturbative regimes of quantum field theories, such as QCD and quantum gravity, are highly relevant for the understanding of fundamental interactions. In this course I will introduce the functional renormalisation group as tool for non-perturbative computations. I will show applications of the functional renormalisation group, where I will put the emphasis on asymptotically safe quantum gravity.*

*Asymptotically safe quantum gravity conjectures a non-trivial ultraviolet fixed point of the renormalisation group flow of the gravitational couplings, which makes the theory non-perturbatively renormalisable and thus fundamental. I will review the evidence in favour of this quantum gravity scenario and show how Standard Model parameters can be post-dicted by it.*

*Bottom-up Holography and its Applications*
by Andrea AMORETTI (INFN, Genova)

*The main goal of the course is to provide an overview of bottom-up models of holography applied to condensed matter systems.*

*The bottom up approach consists in applying the AdS/CFT duality starting directly from a classical gravity model, without caring about its possible string theory embedding. After introducing the basic idea beyond the holographic principle, I will describe the advantages and the limitations of the bottom-up approach. Eventually I will outline the properties of the most relevant bottom-up holographic models appeared in the literature, discussing their applications to study the transport properties of strongly coupled condensed matter systems.*



## PARTICIPANTS

Amoretti Andrea (INFN, Genova)

De Clerck Marine (VUB)

De Filippi David (Umons)

Dimitrov Vasil (KU Leuven)

Fiorucci Adrien (ULB)

Fransen Kwinten (KU Leuven)

Globlek Fran (SISSA)

Goncharov Yegor (Umons)

Grimminger Julius (Imperial College London)

Höhn Philipp (University of Vienna)

Lafay Augustin (LPENS Paris)

Liu Yan (ULB)

Mammadova Leyli (KU Leuven)

Martin-Dussaud Pierre (Centre de Physique Théorique, Aix-Marseille Université)

Naegels Daniel (ULB)

Nguyen Kévin (VUB)

Niro Pierluigi (ULB/VUB)

Noris Ruggero (Polytechnic of Turin)

Pasternak Antoine (ULB)

Peelaers Wolfger (Oxford University)

Pérez Ipiña Juan Manuel (Oxford University)

Radhakrishnan Rajath (Queen Mary University of London)

Reichert Manuel (University of Southern Denmark)

Ruzziconi Romain (ULB)

Scanavino Marcello (University of Genoa)

Schepers Lucas (Swansea University)

Sevim Sinan (Istanbul Technical University)

Valette Guillaume (ULB)

Van Hemelryck Vincent (KU Leuven)

Vandermiers Quentin (ULB)

# AMSTERDAM-BRUSSELS-GENEVA-PARIS DOCTORAL SCHOOL

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).

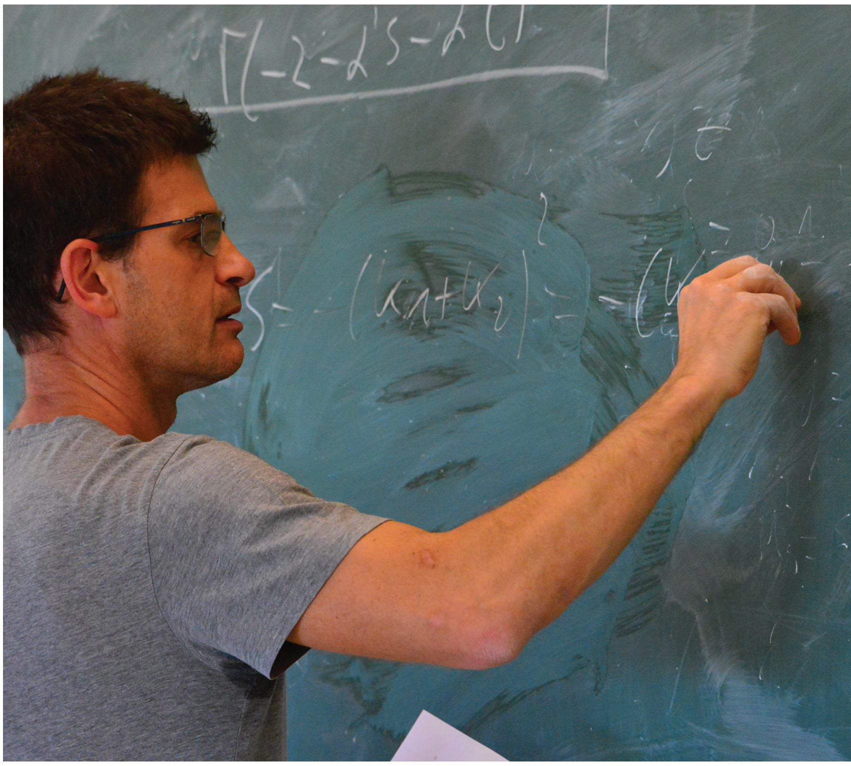
The program typically starts at the end of September/beginning of October and consists of three times three weeks of lectures in three cities among Amsterdam, Brussels, Geneva (CERN) and Paris (depending on the year), with a one-week break between the segments. This way, the students are exposed to several 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 neighboring institutes and countries, who will be their peers and colleagues throughout (and possibly beyond) their PhD studies.

## ORGANIZING COMMITTEE BRUSSELS

Riccardo Argurio I ULB
Ben Craps I VUB
Frank Ferrari I ULB

## PARTICIPATING INSTITUTIONS

- Institute for theoretical physics - University of Amsterdam
- Laboratoire de physique théorique - Ecole Normale Supérieure - Paris
- Physique théorique et mathématique - ULB, Brussels
- Theoretical particle physics - VUB, Brussels
- SwissMap - ETH, U. Bern, U. Geneva, CERN



## PROGRAMME

**Paris I 7 - 25 October**

| | |
|---|---|
| *String Theory I* | Alberto Lerda |
| *String Theory II* | Marco Billò |
| *Advanced GR* | Monica Guica |
| *Advanced Quantum Field Theory* | Adel Bilal |

**Geneva I 4 - 22 November**

| | |
|---|---|
| *Introduction to AdS/CFT* | Julian Sonner |
| *Introduction to Supersymmetry* | Nikolay Bobev |
| *Introduction to Supergravity* | Antoine van Proeyen |
| *Introduction to Superstrings* | Susanne Reffert |

**Amsterdam I 2 - 20 December**

| | |
|---|---|
| *Resurgence* | Marcel Vonk |
| *Modern methods in QFT* | Agnese Bissi |
| *Quantum information* | Michael Walter |
| *AdS/CFT* | Kyriakos Papadodimas |

## PARTICIPANTS

Bahman Najian (University of Amsterdam, The Netherlands)

Chandra A. Ramesh (University of Amsterdam, The Netherlands)

Druart Adrien (Université Libre de Bruxelles, Belgium)

Francois Stéphane (Luleå Tekniska Universitet, Sweden)

Hacker Philip (Vrije Universiteit Brussel, Belgium)

Houppe Anthony (Université Paris Sud, France)

Jaramillo Duque David (École Normale Supérieure, France)

Kalogerakis Ioannis (U. Bern, Switzerland)

Knighton Robert (ETH Zurich, Switzerland)

Marucha Jan (EPFL Lausanne, Switzerland)

Morvan-Benhaim Edward (University of Amsterdam, The Netherlands)

Pallikaris Konstantinos (University of Tartu, Estonia)

Papadopoulos Vassilis (ENS Paris, France)

Rondeau François (LPTHE Paris, France)

Sánchez Garrido Adrián (University of Geneva, Switzerland)

Pekar Simon (Université de Mons, Belgium)

Sterckx Colin (Université Libre de Bruxelles, Belgium)

Van der Heijden Jeremy (University of Amsterdam, The Netherlands)

Zenoni Nicolò (KU Leuven, Belgium and Università Cattolica del Sacro Cuore, Brescia, Italy)

Zhidkova Sofia (Vrije Universiteit Brussel, Belgium)

## STUDENT'S OPINION

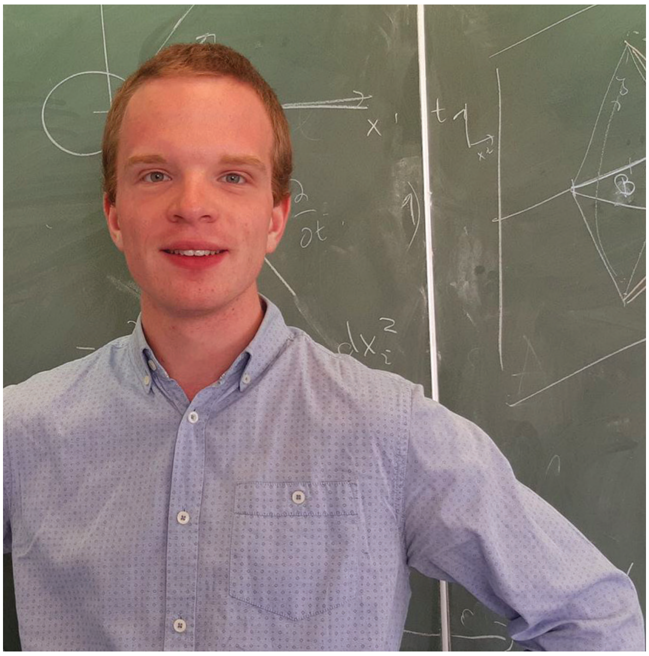
As it has now become a tradition in the mathematical physics group of the ULB, my PhD student life started with the Solvay Doctoral School. My research interests – which mainly focus on classical General Relativity – lying a little bit aside from the main flow of the work carried out in our service, I decided to take part only to the first of the three sessions of the school.

This year introductory session was taking place in Paris at Institut Henri Poincaré. Those three weeks were the opportunity for me to follow pleasant (and intense!) lectures about string theory, advanced gravitation and quantum field theory. In addition of being a perfectly well-designed bridge filling the gap between master-level lectures and research-level requirement, this period was for me a unique occasion to broaden my scientific knowledge of topics not directly related to my thesis program.

The social aspect of the school was also really interesting, as it allowed me to meet many other PhD students coming from all over Europe (and even from further). Exchanging about our respective backgrounds and experiences in such a casual atmosphere was very instructive and fruitful.

In definitive, the Solvay Doctoral School was in every facet a pleasant way to start my PhD!

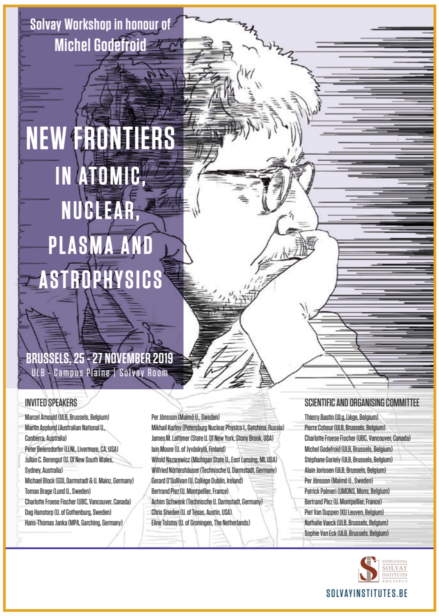
Adrien Druart



## WORKSHOP ON

# “NEW FRONTIERS IN ATOMIC, NUCLEAR, PLASMA AND ASTROPHYSICS”

## 25 - 27 NOVEMBER 2019




This workshop, in honour of Michel Godefroid, aimed to bring together experts from different research fields including atomic, nuclear, plasma and astrophysics to discuss interdisciplinary aspects related to:

- Computational atomic and nuclear structures
- Electron correlation and relativity in atomic physics
- Atomic energy levels, transition rates, hyperfine structures and isotope shifts, electron affinities
- Observational atomic spectroscopy in nuclear, plasma and astrophysics
- Atomic and nuclear data in stellar models
- Heavy, Superheavy elements and exotic nuclei
- Negative ions and highly charged ions

These aspects were covered through the following dedicated sessions:

- Nuclear Astrophysics and Nucleosynthesis
- Stellar Abundances and Atmospheric Models
- Laser Spectroscopy Studies of Exotic Nuclei and Heavy Elements
- Computational Atomic and Nuclear Structures for Nuclear, Plasma and Astrophysics
- Atomic Spectroscopy for Nuclear, Plasma and Astrophysics
- New developments in Theoretical Atomic and Nuclear Physics

## SCIENTIFIC & ORGANIZING COMMITTEE

Thierry Bastin (ULg, Liège, Belgium)
Pierre Coheur (ULB, Brussels, Belgium)
Charlotte Froese Fischer (UBC, Vancouver, Canada)
Michel Godefroid (ULB, Brussels, Belgium)
Stéphane Goriely (ULB, Brussels, Belgium)
Alain Jorissen (ULB, Brussels, Belgium)
Per Jönsson (Malmö U., Malmö, Sweden)
Patrick Palmeri (UMONS, Mons, Belgium)
Bertrand Plez (U. Montpellier, Montpellier, France)
Piet Van Duppen (KU Leuven, Leuven, Belgium)
Nathalie Vaeck (ULB, Brussels, Belgium)
Sophie Van Eck (ULB, Brussels, Belgium)

## INVITED SPEAKERS

Marcel Arnould (ULB, Brussels, Belgium)
Martin Asplund (Australian N. U., Canberra, Australia)
Peter Beiersdorfer (LLNL, Livermore, CA, USA)
Julian C. Berengut (U. of New South Wales, Sydney, Australia)
Michael Block (GSI, Darmstadt & U. Mainz, Germany)
Tomas Brage (Lund U., Sweden)
Charlotte Froese Fischer (UBC, Vancouver, Canada)
Dag Hanstorp (U. of Gothenburg, Sweden)
Hans-Thomas Janka (MPA, Garching, Germany)
Per Jönsson (Malmö U., Sweden)
Mikhail Kozlov (Petersburg Nuclear Physics I., Gatchina, Russia)
James M. Lattimer (State U. of New York, Stony Brook, USA)
Iain Moore (U. of Jyväskylä, Finland)
Witold Nazarewicz (Michigan State U., East Lansing, MI, USA)
Wilfried Nörtershäuser (Technische U. Darmstadt, Germany)
Gerard O'Sullivan (U. College Dublin, Ireland)
Bertrand Plez (U. Montpellier, France)
Achim Schwenk (Technische U. Darmstadt, Germany)
Chris Sneden (U. of Texas, Austin, USA)
Eline Tolstoy (U. of Groningen, The Netherlands)

## CONTRIBUTED TALKS

Carlos Abia (University of Granada, Spain)
Alain Coc (CSNSM, Orsay, France)
Ruben de Groote (University of Jyväskylä, Finland)
Giulio Del-Zanna (University of Cambridge, UK)
Rafael Ferrer (KU Leuven, Belgium)
Jon Grumer (Uppsala University, Sweden)
Henrik Hartman (Malmö University, Sweden)
Stéphane Hilaire (CEA, DAM, DIF, Arpajon, France)
Paul Indelicato (Sorbonne Université, France)
Alex Lobel (Royal Observatory, Brussels, Belgium)
Georges Meynet (University of Geneva, Switzerland)
Gerda Neyens (CERN, Geneva, Switzerland)
Norbert Przybilla (Universität Innsbruck, Austria)

## PROGRAMME

### Monday 25 November 2019

| | |
|---|---|
| Charlotte Froese Fischer | *Opening Remarks: In the beginning* |
| Marcel Arnould | *When Michel's favorite tiny electrons fool the big atomic nuclei in the skies* |
| Alain Coc | *Precision big bang nucleosynthesis* |
| Chris Sneden | *The Impact of improved Atomic Physics on the Chemical Compositions of Low Metallicity Stars* |
| Carlos Abia | *A new assessment of the solar s-and r-process components from a galactic chemical evolution with rotating massive stars yields* |
| Peter Beiersdorfer | *Advanced in the Spectroscopy of Highly Charged Ions for Astrophysics, Plasma Science and Fundamental Physics* |
| Norbert Przybilla | *Quantitative Spectroscopy of Early B-Type Stars: the Impact of High-Quality Atomic Data* |
| Tomas Brage | *Computational Atomic Structure for Plasma and Astrophysics* |
| Henrik Hartman | *Laboratory Atomic Spectroscopy for Near-infrared Astrophysics* |
| Hans-Thomas Janka | *Stellar Explosions and Nucleosynthesis* |
| Georges Meynet | *Rotating massive stars as sources of fluorine 19 through their winds* |
| Wilfried Nörtershäuser | *Recent Results and Prospects for the Laser Spectroscopic Determination of Nuclear Charge Radii* |
| Poster Session | |

### Tuesday 26 November 2019

| | |
|---|---|
| James Lattimer | *Dense Matter Equation of State from Compact Object Mergers* |
| Stéphane Hilaire | *Nuclear reaction ingredients based on the Gogny interaction* |
| Jon Grumer | *Kilonovae and the origin of the R-process elements -Lanthanide atomic data and Non-LTE radiative transfer modelling* |
| Per Jönsson | *New developments in relativistic multiconfiguration calculations* |
| Giulio Del-Zanna | *Atomic data and solar spectral diagnostics, from the X-rays to the near infrared* |
| Bertrand Plez | *Atoms and Molecules in Stellar Atmospheres* |
| Julian C. Berengut | *Precision calculations of atomic and ionic spectra and searches for new physics* |
| Iain Moore | *Laser spectroscopy as a probe for the size and shape of exotic nuclei* |

Ruben de Groote — *New Frontiers in optical spectroscopy of radioactive nuclei: a case study on the silver isotopes*

Achim Schwenk — *Nuclei and matter: from fundamental interactions to structure and stars*

**Solvay Colloquium**

Eline Tolstoy — *Galactic Paleontology*

**Wednesday 27 November 2019**

Martin Asplund — *Precision Stellar Spectroscopy*

Alex Lobel — *The Belgian repository of fundamental atomic data and stellar spectra BRASS*

Paul Indelicato — *Testing Bound-state Quantum electrodynamics with muonic and antiprotonic atoms*

Gerard O'Sullivan — *Spectroscopy to support short wavelength light source development*

Ephraim Eliav — *Atomic electronic structures at the edge of Periodic Table*

Witold Nazarewicz — *Is there an end to the periodic table?*

Michaël Block — *Laser Spectroscopy of Heavy and Superheavy Elements*

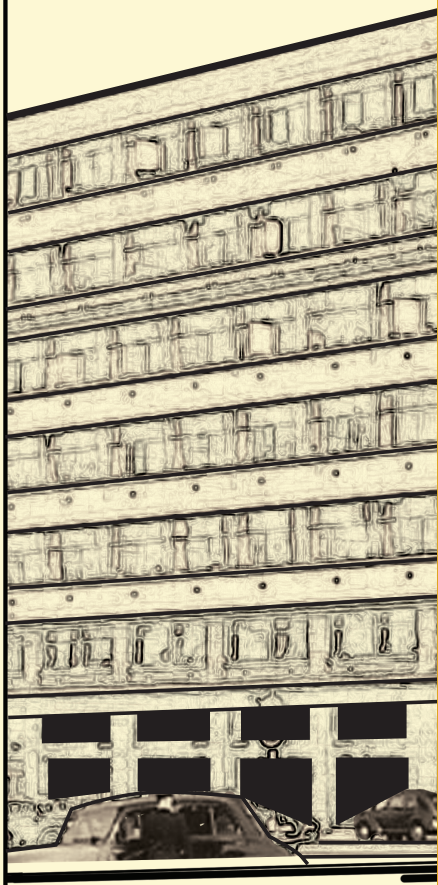
Gerda Neyens — *Short-live radioactive (RaF) molecules: a new perspective for fundamental symmetry studies*

Rafael Ferrer — *High-resolution Laser Ionization Spectroscopy of Heavy Elements in Supersonic Gas Jets*

Mikhail Kozlov — *Theory of polyvalent atoms*

Dag Hanstorp — *Laser spectroscopy of radioactive and stable negative ions*

Closing Speech



# STRINGS 2019

JULY 9-13 | 2019

# STRINGS 2019

## 9 - 13 JULY 2019


"Strings" is a series of annual conferences bringing together the community working in String Theory (an area of theoretical physics). It is the major conference in the field. The series started in the 1980s.

Strings 2019 was organized in Brussels at Flagey by a consortium of Belgian Theoretical Physics Groups from various universities (KU Leuven & Kortrijk, UCL, University of Ghent, ULB, University of Mons, VUB) conducted by the International Solvay Institutes, which played a leading role in its scientific and logistical organizations.

The conference lasted five days (9-13 July 2019) and was attended by 500 participants.

## LOCAL ORGANIZING COMMITTEE

| | |
|---|---|
| Riccardo Argurio | ULB |
| Jay Armas | ULB |
| Glenn Barnich | ULB |
| Nikolay Bobev | KU Leuven |
| Nicolas Boulanger | UMONS |
| Andrea Campoleoni | UMONS |
| Andrés Collinucci | ULB |
| Geoffrey Compère | ULB |
| Ben Craps | VUB |
| Stéphane Detournay | ULB |
| David Dudal | KUL, Kortrijk |
| Claude Duhr | UCL |
| Frank Ferrari | ULB |
| Jutho Haegeman | UGent |
| Marc Henneaux (Chair) | ULB |
| Thomas Hertog | KU Leuven |
| Alberto Mariotti | VUB |
| Alexander Sevrin | VUB |
| Antoine Van Proeyen | KU Leuven |
| Thomas Van Riet | KU Leuven |
| Henri Verschelde | UGent |
| Frank Verstraete | UGent |

## SCIENTIFIC PROGRAM COMMITTEE

| | |
|---|---|
| Costas Bachas (Chair) | ENS Paris, France |
| Nikolay Bobev | KUL, Belgium |
| Clay Córdova | Princeton, USA |
| Ben Craps | VUB, Belgium |
| Claude Duhr | UCLouvain & CERN |
| Frank Ferrari | ULB, Belgium |
| Rajesh Gopakumar | ICTS-TIFR, India |
| Sarah Harrison | McGill U., Canada |
| Thomas Hartman | Cornell U., USA |
| Jeff Harvey | U. Chicago, USA |
| Stefan Theisen | Max-Planck, Germany |
| Wei Song | Tsinghua, China |
| Irene Valenzuela | Cornell U., USA |

## REVIEW TALKS

| | |
|---|---|
| Christopher Beem | *Vertex Algebras and Superconformal Field Theories in Four Dimensions* |
| Liam McAllister | *de Sitter space in string theory* |
| Mark Mezei | *The TTbar deformation* |
| Matthew Reece | *The Swampland Program* |
| Henning Samtleben | *Exceptional Field Theory and Applications* |
| Brian Swingle | *Developments in scrambling and chaos* |
| Aron Wall | *Progress in Horizon Thermodynamics* |
| Alberto Zaffaroni | *Progress on AdS Black Holes in String Theory* |

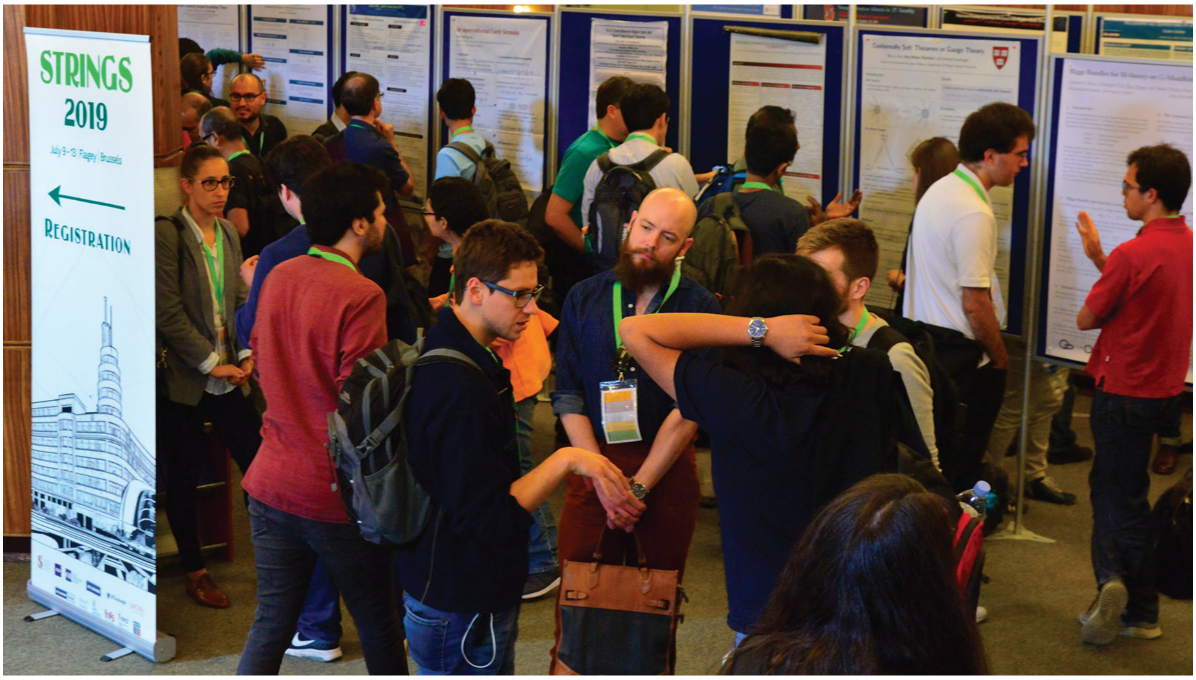
## PLENARY TALKS

| | |
|---|---|
| Ahmed Almheiri | *Unitary Semiclassical Black Hole Evaporation* |
| Zvi Bern | *Orbital Dynamics for LIGO/ Virgo from the Double Copy and EFT* |
| Agnese Bissi | *Genus one string amplitudes from CFT* |
| Simon Caron-Huot | *Unreasonable simplicity of AdS5xS5 correlators* |
| Alejandra Castro | *Siegel paramodular forms* |
| Jan de Boer | *Sewing entanglement wedges* |
| Xenia de la Ossa | *Moduli spaces in heterotic string theory* |
| Lorenz Eberhard | *An exact* $AdS_3/CFT_2$ *duality* |
| Monica Guica | *Irrelevant current-current deformations and holography* |
| Song He | *Generalized particles and strings from combinatorial geometry* |
| Veronika Hubeny | *Holographic Entropy Relations* |
| Seok Kim | *AdS black holes and Cardy limits* |
| Zohar Komargodski | *Extremal Correlators in Four Dimensions* |
| Kantaro Ohmori | *'t Hooft Anomaly, Symmetry breaking, Gaplessness* |
| Hirosi Ooguri | *Bounds on Mellin > Amplitudes* |
| Juan Maldacena | *Comments on the Hartle Hawking wave function of the universe* |
| Marcos Mariño | *Resurgence and BPS states* |
| Dalimil Mazac | *Sphere Packing and Quantum Gravity* |
| Eran Palti | *Light towers of states in String Theory* |
| Onkar Parrikar | *Quantum Complexity of Time Evolution with Chaotic Hamiltonians* |
| Elli Pomoni | *T_N, Toda and topological strings* |
| Ashoke Sen | *Analyticity properties of superstring loop amplitudes* |
| Stephen Shenker | *Black holes, random > matrices, baby universes, and D-branes* |
| Andrew Strominger | *Critical Theory and Interferometric Observation of the M87 Photo Ring* |
| Alessandro Tomasiello | *String theory < compactifications with sources* |
| Sandip Trivedi | *Near-Extremal Black Holes and the Jackiw-Teitelboim Model* |
| Pedro Vieira | *Octagon(s)* |
| Timo Weigand | *Quantum Gravity Constraints and their Stringy Realisation* |
| Edward Witten | *JT Gravity and Random Matrix Ensembles* |
| Alexander Zhiboedov | *Lightrays, shocks, strings, and conformal colliders* |

## VISION SESSION TALKS

### (Chair: David Gross)

| | |
|---|---|
| Luis Fernando Alday | *Bootstrap, present and future* |
| Nima Arkani-Hamed | *Prospects for contact of string theory with experiments* |
| Daniel Harlow | *Holographic spacetime reconstruction and related topics* |
| Nathan Seiberg | *Quantum Field Theory* |
| Douglas Stanford | *Quantum chaos and its relation to gravity* |



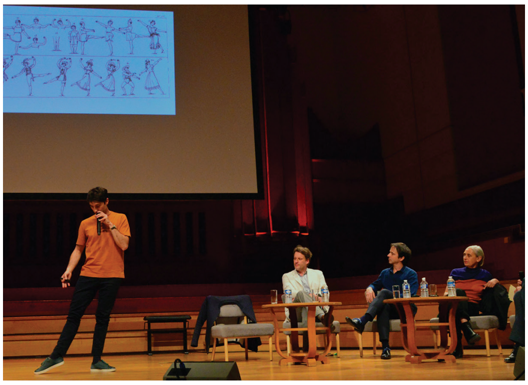

## GONG SHOW

(Chair: Yaron Oz)

| | |
|---|---|
| Alex S. Arvanitakis | *The L-infinity algebra of the S-matrix* |
| Chris Blair | *Orbifolds and Orientifolds as O-folds* |
| Nele Callebaut | *Jackiw-Teitelboim dynamics of entanglement in boundary CFT* |
| Federico Carta | *SUSY enhancement, T-branes and Hitchin systems* |
| Hongbin Chen | *Exact Bulk Reconstruction, bulk locality, and black hole horizons* |
| Andrea Dei | *Integrability and stringy WZW models* |
| Adwait Gaikwad | *Gravitational collapse in SYK models and Choptuik-like phenomenon* |
| Yuta HamadaWeak | *Gravity Conjecture from Unitarity and Causality* |
| Matthew Heydeman | *Six-Dimensional (2,0) Scattering Amplitudes: The M5 Brane and IIB Supergravity on K3* |
| Zhijin Li | *CFT genome project: 3d QED Bootstrap* |
| Matheus Loss Lize | *Field theory actions for ambitwistor string and superstring* |
| Jun Nian | *Microstate Counting of Near-Extremal Black Holes via AdS/CFT Correspondence* |
| Tokiro Numasawa | *Late Time Quantum Chaos of pure states in the SYK model* |
| Sarthak Parikh | *Simplicity of AdS Conformal Block Decomposition* |
| Leonel Queimada | *Holographic Complexity Equals Which Action?* |
| Victor Rodriguez | *Long String Scattering in c = 1 String Theory* |
| Junggi Yoon | *Chaos in Chern-Simons higher spin gravity* |
| Wenli Zhao | *Conformal Window and Symmetry Breaking in Coupled SYK or Tensor Models* |

# TWO CULTURAL EVENTS WERE ORGANIZED AS SATELLITE ACTIVITIES

The first was the dance performance ‘Mitten wir im Leben sind’ by renowned choreographer Anne Teresa De Keersmaeker, preceded by a panel discussion on ‘Gravity in Dance’.



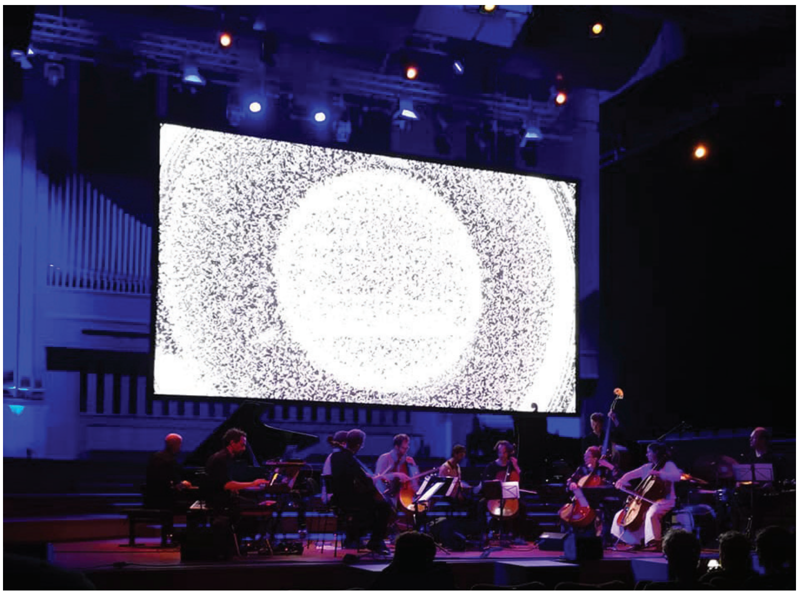

## PANEL MEMBERS

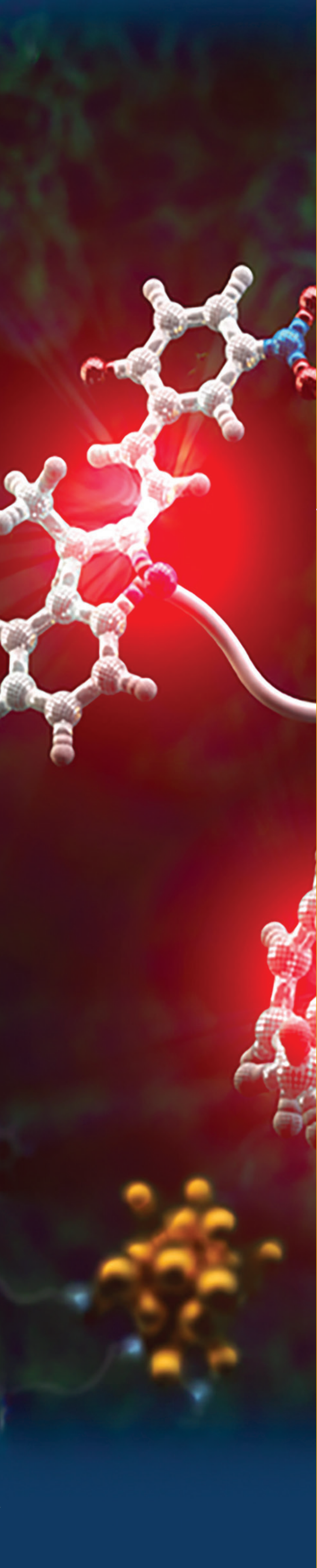
Professor Robbert Dijkgraaf, moderator (director of the IAS, Princeton)
Anne Teresa De Keersmaeker (choreographer)
Professor Thomas Hertog (cosmologist, KU Leuven)
Jean-Guihen Queyras (French cellist)
Noé Soulier (French dancer and choreographer)

The second one was organized by Science and Cocktails.

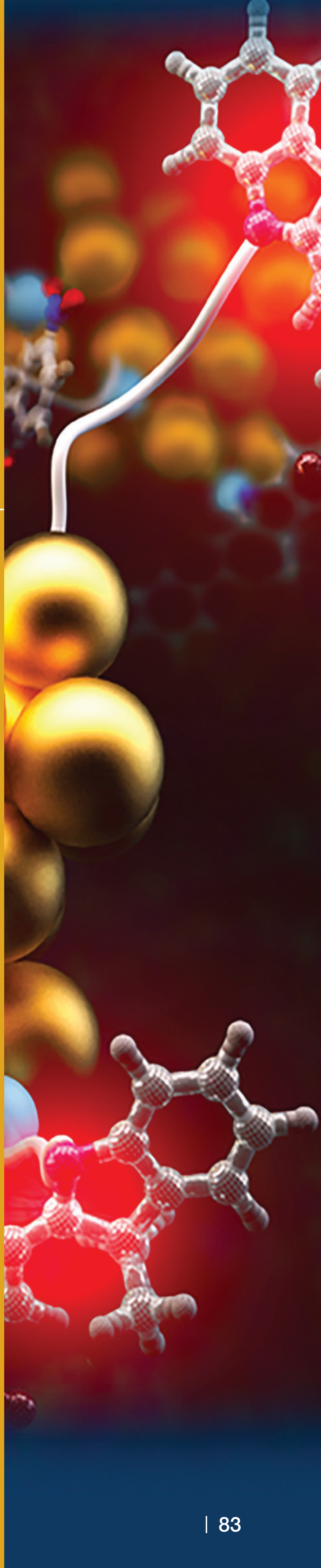
In the framework of the largest string theory conference in the world, Strings 2019, Science and Cocktails organized a special event at Flagey.

Professor Robbert Dijkgraaf gave a lecture about the fundamental laws of Nature. Afterwards, cellist and composer Benjamin Glorieux performed a musical piece together with invited guests especially commissioned for the occasion, while live-video artist Klaas Verpoest accompanied them with his visual magic.



# NEW HORIZONS LECTURES



# NEW HORIZONS LECTURES

The "New Horizons Solvay Lectures" were launched in 2018. The object of the program is to invite a brilliant young scientist (PhD + 12 years maximum) with already high visibility and well-established stature to give a series of lectures in Brussels and in other Belgian universities.

Through this program, the Solvay Institutes wishes to strengthen collaborations between Belgian research teams. Young researchers are the special target, and interactions between them and the Solvay lecturer are maximized.

The success of the 2018 edition convinced the board of the Institutes to continue on a yearly basis.

## 2019 NEW HORIZONS LECTURES IN CHEMISTRY

**Professor Professor Rafal Klajn** I Weizmann Institute, Israel

Professor Professor Rafal Klajn, from the department of organic chemistry at the Weizmann Institute (Israel) was the 2019 "New Horizons Lecturer" in Chemistry.

Professor Klajn's research focuses on supramolecular chemistry, which is the study of entities of greater complexity than individual molecules—assemblies of molecules that bond and organize through intermolecular interactions. He is an expert in developing new "smart" materials by integrating two types of building blocks: nanocrystals and molecular switches. His group has recently fabricated reversible information storage media, in which information can be stored for desired periods of time. The importance of Professor Klajn's remarkable work has been recognized by many awards, including an ERC Starting Investigator Award in 2013.

His lecture at the Solvay Institutes was devoted to a profound question: "Chemistry in confined spaces: Light-controlled reactions in the cavities of metal-organic cages". It was followed by visits to the University of Antwerp and Ghent University. Intense interactions with young researchers took place through seminars and poster discussions in Antwerp, Brussels and Ghent. A participation in a Symposium at the Academy was also included in his visit.

Professor Klajn was hosted by the group of Professor Yves Geerts, who was instrumental in organizing Professor Klajn's stay in Belgium (27-29 March) and the scientific program of his visit. The Solvay Institutes heartily thank him for his efficient help.

# PROGRAMME

Rafal Klajn was born in Poland in 1982. In 2009 he completed his PhD in Chemical and Biological Engineering at Northwestern University (USA). The thesis was dedicated to the development of new functional materials arising from the integration of inorganic nanocrystals with molecular and supramolecular switches. Since 2009, Rafal Klajn is faculty member of the department of Organic Chemistry of the Weizmann Institute of Science, first as assistant professor and since 2016 as associate professor.

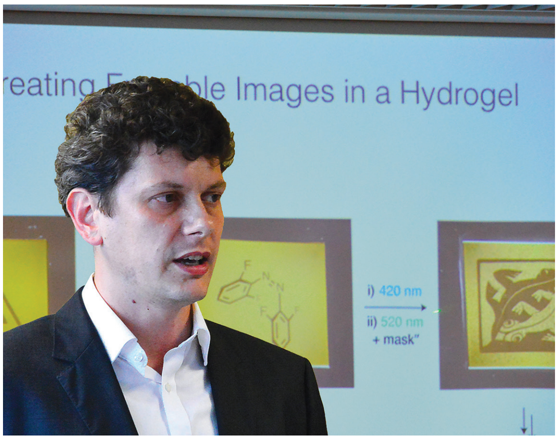
Rafal Klajn is author of more than 50 publications and is recipient of the 2010 IUPAC Prize for Young Chemists, the 2013 ACS Victor K. LaMer Award, a 2013 ERC Starting Investigator Award, and the 2015 Liebig Lectureship (Germany), among other prizes.

## 27 March 2019 at ULB

Lecture and discussions with young researchers.

*"Chemistry in confined spaces: Light-controlled reactions in the cavities of metal-organic cages"*

*Nature has long inspired chemists with its ability to stabilize ephemeral chemical species, perform chemical reactions at unprecedented rates and selectivities, and synthesize complex molecules and inorganic nanostructures with seemingly effortless ease. However, chemists and natural systems perform reactions in fundamentally different ways: whereas chemists typically carry out reactions between molecules moving around freely in solution, natural systems consistently use the effect of nanoscale confinement. During the past several years, our group has been engaged in studying chemical reactivities in various types of confined spaces, including nanopores of porous aromatic frameworks (PAFs), cavities of bowl-shaped inorganic nanoparticles, and dynamically self-assembling nanoflasks. To efficiently guide many key processes in nature, however, confined spaces have to be sufficiently flexible. In synthetic systems, this flexibility aspect is critical for, e.g., efficiently operating single-molecule switches, whose isomerization is often accompanied by significant conformational changes. To this end, we investigated photoisomerization in several classes of light-switchable molecules confined within flexible metalorganic cages. Working with spiropyran switches, we found that the cage had a propensity to stabilize the otherwise unstable, open form of the switch. I will describe how this blue-colored form could be photoisomerized using – counterintuitively – using blue light. These results constitute the first example of negative photochromism of spiropyran in a nonpolar environment. Next, I will discuss encapsulation and switching of several azobenzene derivatives under confinement, focusing on the unexpected finding of light-controlled azobenzene trafficking between different cages. The talk will be concluded by the results of our recent studies on light-induced dimerization of confined anthracenes, from which we concluded that these reactions obey the topochemical rules set half a century ago by Gerhard Schmidt.*




### 28 March 2019 at Antwerp University

Hosted by the group of Professor Sara Bals.

Lecture and discussions with young researchers.

*"Static and dynamic self-assembly of nano-particles and post-assembly modifications of the resulting materials"*

*Self-assembly has emerged as the method of choice for preparing materials made of nanosized particles. Over the past several years, our group has been interested in developing new ways to control self-assembly of inorganic nanoparticles into higher-order, static and dynamic structures. I will begin this talk by discussing our most recent studies on electrostatic self-assembly of oppositely charged nanoparticles. We have conceived a novel method to induce co-assembly of positively- and negatively-charged nanoparticles, which, unlike previously reported methods, maintains the high surface charge on these nanoparticles during the self-assembly process, and leads to previously unknown assemblies. Next, I will introduce ways to control self-assembly of nanoparticles using external stimuli, such as light, magnetic field, and $CO_2$, as well as emerging applications of such nanoparticles. The final part of my talk will focus on post-assembly modifications of nanoparticle aggregates, and will demonstrate that such aggregates can serve as precursors for further transformations. Specifically, I will discuss selective etching of binary nanoparticle superlattices and its use to prepare a novel family of materials, non–close-packed nanoparticle arrays.*

### 29 March 2019 at Ghent University

Hosted by the group of Professor Richard Hoogenboom.

Lecture and discussions with young researchers.

*"Self-assembly of nanoparticles driven by light and chemical fuels"*

Many informal and spontaneous discussions with young scientists took place during the other days of Professor Klajn's visit.

## 2019 NEW HORIZONS LECTURES IN PHYSICS

**Professor Aleksandra Walczak** I ENS Paris, France

The 2019 New Horizons Lectures in Physics were delivered by Professor Aleksandra Walczak, from the Ecole Normale Supérieure in Paris (France).

The precision and reproducibility of cellular processes poses a challenge to many-body physics and our understanding of the physical principles that control the emergent properties of biological systems. Professor Walczak is a world-leading expert in the study of the behaviour of such strongly coupled nonlinear systems that are not in equilibrium, mostly inspired by existing biological solutions. Her work lies in the description of systems on the cellular scale - understanding the link between function, development and evolvability of conserved pathways and their elements, where she made outstanding contributions.

Her lecture at the Solvay Institutes was delivered on April 30 and entitled: "Prediction in Immune Repertoires". A full day at the KUL (group of Professor Lendert Gelens) was also organized on April 29, with a lecture and intense interactions with young researchers.

The visit of Professor Walczak (29 April – 3 May) was organized by Professors Sophie de Buyl (VUB). It is a pleasure to thank her.

Aleksandra Walczak received her PhD in physics at the University of California, working on models of stochastic gene expression. After a graduate fellowship at the Kavli Institute for Theoretical Physics (California), she worked on applying information theory to signal processing in small gene regulatory networks at the Princeton Center for Theoretical Science. Currently based at the École Normale Supérieure as a CNRS researcher, she studies the effects of selection on population genealogies, collective behavior of bird flocks and statistical descriptions of the immune system.

Dr Walczak was awarded the "Grand Prix Jacques Herbrand de l'Académie des sciences" in 2014 and the bronze medal of CNRS in 2016. Her starting ERC project 'RECOGNIZE' focused on the self-organization of the immune repertoire at the molecular and evolutionary level, by using a combination of data analysis and statistical mechanics modelling. Her current consolidator ERC project 'STRUGGLE' explores the statistical physics of immune-viral co-evolution.


## PROGRAMME

### 29 April 2019 at KU Leuven

Hosted by the group of Professor Lendert Gelens.

Lecture and discussions with young researchers.

*"Precision in a rush: decision making in early fly development"*

*Despite very limited time, organisms develop in reproducible ways. In the early stages of fly development positional information is read out in a few minutes to produce steep and precise gene expression patterns — the rough blueprint for future body parts. Motivated by recent live imaging experiments in fly embryos, I will discuss the trade-offs between speed, reproducibility and ease of decoding of the blueprint. I will show strategies that allow for fastest yet accurate decision making in this molecularly noisy system.*

### 30 April 2019 at ULB

Lecture and discussions with young researchers.

*"Prediction in immune repertoires"*

*Our adaptive immune system protects us against a wide variety of different pathogens — many of which were not around when we were born. How can our immune system be prepared for the many unknown pathogens that we will encounter throughout our lives? To make the job harder, the pathogens keep changing and evolving, forcing the immune system to change. In this talk, I will use statistical inference to quantify how nature uses statistics to generate diversity and be prepared to respond to many challenges. I will also describe stochastic prediction strategies that are consistent with our vision of this self-organised protection system.*

Informal and spontaneous discussions with young scientists took place during the other days of Professor Walczak's visit.

Interactions with the Institute for Bioinformatics (https://ibsquare.be) also took place on May 3.

# COLLOQUIA

# COLLOQUIA

## THERE IS PLENTY OF ROOM AT THE BOTTOM… BUT EVEN MORE IN A FRACTAL

**Professor Cristiane Morais Smith**

Utrecht University, The Netherlands

29 January 2019

Feynman's original idea of using one quantum system that can be controlled and manipulated at will to simulate the behavior of another more complex one has flourished during the last decades in the field of cold atoms. More recently, this concept started to be developed in nanopho-tonics and in condensed matter. In this talk, I will discuss a few recent experiments, in which 2D electron lattices were engineered on the nanoscale. The first is the Lieb lattice [1], and the second is a Sierpinski gasket [2], which has dimension D = 1.58. The realization of fractal lattices opens up the path to electronics in fractional dimensions. Finally, I will show how to control the electronic orbital degree of freedom [3] and how to realize topological states of matter using the same procedure. In all cases, we observe an excellent agreement between the theoretical predictions and the experimental results. This technique is proving itself to be a very versatile framework for the engineering and control of electronic systems.

*[1] M.R. Slot, T.S. Gardenier, P.H. Jacobse, G.C.P. van Miert, S.N. Kempkes, S.J.M. Zevenhuizen, C. Morais Smith, D. Vanmaekelbergh, and I. Swart, "Experimental realisation and characterisation of an electronic Lieb lattice", Nature Physics 13, 672 (2017). [2] S.N. Kempkes, M.R. Slot, S.E. Freeney, S.J.M. Zevenhuizen, D. Vanmaekelbergh, I. Swart, and C. Morais Smith, "Design and characterization of electronic fractals", arXiv:1803.04698, in print Nature Physics (2019). [3] M. R. Slot et al., "p-band engineering in artificial electronic lattices", in print Phys. Rev. X (2019).*

# EXPLORING UNCONVENTIONAL SYNTHETIC ROUTES BY THE USE OF HIGH PRESSURE

**Professor Roberto Bini**

LENS, Florence, Italy

5 February 2019

Pressures larger than 1 GPa are uncommon in laboratory synthetic processes in spite of representing a normal condition in Nature. The study of the pressure effects on molecular systems, including the simplest ones, is therefore a prerequisite to understand chemical and physical properties of the Earth's interior as well as of outer planets and satellites. The high-pressure chemistry of molecular systems is a fascinating world characterized by unusual behaviors with respect to ambient conditions whose achievements often challenge consolidated assumptions in the chemical community. Pressure is indeed able to efficiently reduce the intermolecular distances creating configuration interactions uncommon at ambient conditions. The information about the reactivity at the molecular level which can be gained by high pressure studies has a two-fold importance. From fundamental point of view, since the reactivity takes place in condensed phases, they represent an invaluable tool for providing insight about the mechanisms regulating solid state chemistry. From applicative point of view, the search for new exciting materials and the way to scale down the synthesis conditions is an emerging research field.

In this talk the reactivity and the structural modifications induced by pressure will be reviewed for several model molecular systems, from simple diatomics to aromatic crystals. In addition to the obvious relationship between structure and reactivity also the role that temperature and light play, in combination with pressure, on the reactivity will be also taken into account. The control of the three parameters represents an important source of information for understanding the reactive mechanisms at the molecular level and then for making the synthesis conditions as little drastic as possible. A particular attention will be dedicated to the recent synthesis of carbon nanothreads which represent an enlightening example of the role that anisotropic stress can play in high pressure reactions.

# FUNDAMENTAL CONSTANTS, GRAVITATION AND COSMOLOGY

**Professor Jean-Philippe Uzan**

IAP, Paris, France

12 February 2019

Fundamental constants are a cornerstone of the physical laws. Any constant varying in space and/or time would reflect a violation of Einstein equivalence principle. Thus, it is of importance for our understanding of gravity and of the domain of validity of general relativity to test for their constancy.

I will first recall the relations between the constants, the tests of the local position invariance and of the universality of free fall and discuss their role in the new definition of the International System of units voted on Nov. 16th 2018.

I will then sketch the main theoretical frameworks in which the low-energy constants may actually be varying. Many experimental and observational constraints have been obtained from atomic clocks, the Oklo phenomenon, solar system observations, meteorite dating, quasar absorption spectra, stellar physics, pulsar timing, the cosmic microwave background and big bang nucleosynthesis.

I will provide a summary of these observations and of the recent developments of the field.

## FROM "COGNITIVE-TYPE" NEURAL MICROCIRCUITS TO THE GLOBAL BRAIN

**Professor Xiao-Jing Wang**

NYU, USA

19 March 2019

I will discuss Theoretical Neuroscience as it pertains to brain structures dedicated to cognitive abilities rather than sensation or movement, such as how we hold and manipulate information in mind and how we make a difficult decision. These circuits are non-linear stochastic dynamical systems characterized by a duality of slow transients and attractor dynamics. More recently we developed large-scale modeling of mammalian neocortex, based on mesoscopic directed- and weighted inter-areal connectivity data. Advances in this research program will provide a theoretical framework for investigating how such a complex brain system with more than 100 parcellated areas underlies cognition and flexible behavior, as well as new ideas for artificial intelligence and deficits associated with mental illness.

## ELECTROWEAK SYMMETRY BREAKING AND NEW PHYSICS: A LOVE AFFAIR

**Professor Christophe Grojean**

DESY, Germany

7 May 2019

The electroweak scalar, also known as the Brout-Englert-Higgs boson, is a tool for exploration as much as a standalone topic of investigation. While it appears very much Standard Model-like from the portrait drawn at the LHC, it remains at the heart of most Beyond the Standard Model scenarios, mostly because of the still unanswered question of naturalness and its possible connection to the puzzle of matter-anti-matter imbalance.

I shall browse through a selection of new physics models and present their main signatures at present and future colliders.

Finally, I shall mention some complementary information that can be gleaned beyond colliders.

# MOLECULAR MECHANISMS OF EXCITATORY NEUROTRANSMITTER TRANSPORT

**Professor Nicolas Reyes**

Institut Pasteur, Paris, France

14 May 2019

Solute carriers constitute a large superfamily of integral membrane proteins that move essential solutes across membrane in all kingdoms all life. The solute carrier 1 family (SLC1) includes sodium-dependent transporters of acidic and neutral amino acids. In humans, SLC1 proteins are key regulators of extracellular glutamate in the central nervous system, and constitute important pharmaceutical targets in neurodegeneration and several forms of cancer.

During my talk, I will discuss structural and mechanistic aspects of the function and pharmacology of human and prokaryotic SLC1 homologs, with a focus on glutamate or excitatory neurotransmitter transport.

# ORIENTED ELECTRIC FIELDS - NEW EFFECTORS IN CHEMISTRY


**Professor Sason Shaik**

Hebrew University, Israel


1 October 2019

The talk will discuss the wide-ranging potential of using oriented external-electric-fields (OEEFs) as new effectors of chemical change.[1-5] Generally speaking, an OEEF along the direction of electron reorganization from reactants to products, will catalyze/inhibit at will non-polar reactions, while orientations of the OEEF off the "reaction axis" will control selectivity patterns and chiral discrimination.[1,3] The field's direction will similarly affect bonds, molecular structures and aggregation.[5]

I shall discuss OEEF effects, using a selection from the following topics: (a) Control of bond length and strength, and molecular structures, (b) control, at will, of non-redox chemical reactions by catalyzing or inhibiting them through a flip of the field's direction, (c) control of regioselectivity (e.g., C=C vs C-H activation by oxoiron reagents (e.g., P450 like),[1,5] exo/endo selectivity in Diels-Alder reactions),[1,5] (d) control of spin-state selectivity,[1,5] (e) control of reaction mechanisms,[1,5] (f) the dilemma of electric fields in enzymes, 5 and (g) control of chiral discrimination and enantioselectivity.[3] Some future prospects may be discussed as well: (a) the ability of OEEF to act as tweezers that orient the reactants in space and catalyzes their reactions, (b) the role of OEEFs in self-assembly.

As shall be described, there are by now a variety of experimental techniques to implement the OEEF idea,[2,5] including scalable options.[2b] The field is rapidly expanding. As experimental techniques mature further, chemical transformations may become an exercise in zapping oriented molecules with OEEFs.


*1 Shaik, S.; Mandal, D.; Ramanan, R. Oriented Electric Fields as Future Smart Reagents in Chemistry, Nature Chem. 2016, 8, 1091 (2016).*

*2 (a) Aragonès, A. C.; Haworth, N. L.; Darwish, N.; Ciampi, S.; Bloomfield, N. J.; Wallace, G. G.; Diez-Perez, I.; Coote, M.L. Electrostatic catalysis of a Diels–Alder reaction, Nature, 2016, 531, 88– 91;*

*(b) The use of electric fields to catalyse chemical reactions is in principle scalable. See: Lin, Z.; Zeng, X.; Yu, S. Enhancement of Ethanol-Acetic Acid Esterification Under Room Temperature and Non-Catalytic Condition via Pulsed Electric Field Application. Food Bioprocess Technol. 2012, 5, 2637-2645*

*3 Wang, Z.; Danovich, D.; Ramanan, R.; Shaik, S. Oriented-External Electric Fields Create Absolute Enantioselectivity in Diels-Alder Reactions: Importance of the Molecular Dipole Moment. J. Am. Chem. Soc. 2018, 140, 13350-13359.*

*4 See a recent feature article by J. Howgego [a feature editor at New Scientist]: Field of Influence, Chemistry World, 2018, 22 January 2018, 1-9.*

*5 For a tutorial, see: Shaik, S.; Ramanan, R.; Danovich, D.; Mandal, D. Structure and Reactivity/Selectivity Control by Oriented External Electric Fields. Chem. Soc. Rev. Tutorial, 2018, 47, 5125-5145.*

# GALACTIC PALAEONTOLOGY

**Professor Eline Tolstoy**

University of Groningen, The Netherlands

26 November 2019

I will talk about how observations of resolved stellar populations are being used to study the ancient fossil record of the formation and evolution of stars and the resulting chemical element production in nearby galaxies. This can only be done nearby, as it requires accurate colours, variability, chemical abundances and kinematic measurements of large samples of individual low mass stars from deep imaging and spectroscopy surveys. These studies provide detailed insights into galaxy evolution going back to the early Universe.

I will concentrate on what we can learn from the smallest and simplest of galaxies, the so-called dwarf galaxies, but I will also make the link to our increasingly detailed understanding of our home galaxy, the Milky Way, and the role that chemical elements play in disentangling the story of all galaxies.

# THE PHYSICS OF JAMMING: A JOURNEY FROM MARBLE PEBBLES TOWARD SCALING INVARIANT FIELD THEORY

**Professor Giorgio Parisi**

Università La Sapienza, Roma, Italy

10 December 2019

The physics of jamming: a journey from marble pebbles toward scaling invariant field theory Jamming is a well-known phenomenon that you have experienced when the traffic is very heavy. You cannot move because your neighbors block you and your neighbors cannot move because you block them. Jamming is a collective phenomenon.

Marble pebbles on the beach are one example of jamming. However also for well-levigated pebbles, friction will play an important role.

Statistical mechanics may be used to study the case of systems without friction. The most studied case is the hard-sphere gas where the jamming point is reached in the limit of infinite pressure. In the case of frictionless jamming long-range correlations are present: we have a new kind of critical system.

Recently the properties of the hard-sphere gas have been analytically computed in the framework of the mean-field approximation. Non-trivial critical exponents have been found.

The behavior of the correlation functions at large distances has not yet computed (it is technically very challenging): at the end one should find a new scaling invariant field theory.

# WORKSHOPS AND ACTIVITIES

## SPONSORED BY THE INSTITUTES

## COLLOQUIUM

# "QUANTUM INFORMATION: THE SECOND QUANTUM REVOLUTION?"

Brussels, 30 March 2019

Palace of the Academies

Organised by the National Committee for Pure and Applied Physics

## PROGRAMME

Prof. David DIVINCENZO
(FZ Juelich and RWTH Aachen)
*Introduction to Quantum Information.*

Prof. Dorit AHARONOV
(Hebrew Univ. Jerusalem)
*Quantum Computing, Conceptual Aspects and Challenges.*

Poster Session by the Belgian Research Institutions

Prof. Anton ZEILINGER
(IQOQI, Vienna)
*Quantum Communication and Encryption.*

Prof. Immanuel BLOCH
(MPI Quantum Optics, Garching)
*Quantum Simulations for Condensed Matter Physics.*

Prof. Vijay BALASUBRAMANIAN
(Univ. Pennsylvania)
*Combining High Energy Physics and Quantum Information Theory.*

Closing and Reception

# STRINGS, COSMOLOGY AND GRAVITY STUDENT CONFERENCE

Munich, 1-3 April 2019

The 2019 edition of the Strings, Cosmology, and Gravity Student Conference took place at the Max-Planck-Institut für Physik in Munich, from the 1st to the 3rd of April.

The conference was designed to bring together PhD and postdoctoral researchers in their early career working in theoretical high energy physics, especially in the areas of string theory, cosmology, and gravity. One of the primary aims was to give attendees the opportunity to present their research via contributed talks and to form collaborations. The conference was open to all interested graduate students and postdoctoral researchers. Applications from women and other underrepresented groups were encouraged.

Alongside the talks enough space was made for the researchers to discuss their work and the future of research in theoretical high energy physics. Registered participants were also able to present their work in a poster session.

This was the 10th anniversary of the SCGSC conference.

## ORGANIZING COMMITTEE

Lars Aalsma (UvA)
Lilian Chabrol (IPhT)
Marine De Clerck (VUB)
David Ho (ICL)
Daniel Klaewer (MPP)
Grégoire Mathys (UvA)
David Osten (MPP)
Antonio Rotundo (UvA)
Matthias Traube (MPP)
Guillaume Valette (ULB)
Stav Zalel (ICL)

# BPS ANNUAL CONFERENCE

Brussels, 22 May 2019

## ORGANIZING COMMITTEE

Prof. Barbara Clerbaux (ULB)

Prof. Gilles De Lentdecker (ULB, *Vice-president of the BPS*)

Prof. Thomas Gilbert (ULB)

Prof. Patricia Losada Perez (ULB)

Prof. Simone Napolitano (ULB)

Prof. Simona Toscano (ULB)

Prof. Peter Schlagheck (ULiege)

## SCIENTIFIC COMMITTEE

Prof. Barbara Clerbaux (ULB)

Prof. Gilles De Lentdecker (ULB)

Prof. Thomas Gilbert (ULB)

Prof. Patricia Losada Perez (ULB)

Prof. Fabrice Louche (RMA)

Prof. Simone Napolitano (ULB)

Prof. Jozef Ongena (RMA, *President of the BPS*)

Prof. Simona Toscano (ULB)

Prof. Xavier Urbain (UCLouvain)

## PLENARY LECTURES

*The MYRRHA project*
Prof. Hamid Aît Abderrahim (SCK-CEN, Mol, Belgium)

*Physics of matter under intense radiation fields under study at the ELI and Laser Megajoule laboratories*
Prof. Vladimir Tikhonchuk ( Centre Lasers Intenses et Applications, University of Bordeaux, France and Extreme Light Infrastructure, Prague, Czech Republic )

## PARALLEL SESSIONS

- Fundamental Interactions, Particle and Nuclear Physics
- Condensed Matter and Nanostructure Physics
- Bio-, Medical, Statistical & Mathematical
- Atoms, Molecules, Optics, and Photonics
- Astrophysics, Geophysics, and Plasma Physics
- Physics and Education

## ORAL PRESENTATIONS OF THE YOUNG SCIENTIST CONTEST

- Marco Di LIBERTO (ULB): “Realization of Aharonov-Bohm Cages in Photonic Lattices”
- Daniela MOCKLER (ULB): “Measurement of the cosmic ray spectrum with the Pierre Auger Observatory”
- Johan van der TOL (KULeuven): “Cluster gasses: when the equipartition theorem looses its validity”

# MEETINGS OF THE BELGIAN QUANTUM PHYSICS INITIATIVE

Brussels, Académie Royale de Belgique

The Meetings of the Belgian Quantum Physics Initiative (BQPi) are scientific meetings that are organized at the Royal Academy of Belgium since November 2017.

They are co-organized by groups in Ghent, Antwerp, Brussels, Hasselt, Liège, Namur and Leuven Universities. They aim to trigger and encourage interactions among physicists who are active in the many areas of quantum physics (such as condensed-matter physics, quantum optics, quantum information and quantum computing) in Belgium, in particular young researchers and phD students. Each meeting is structured in three parts: the meeting starts with a one-hour Colloquium, presented by an eminent scientist; then discussions take place over a long coffee-break; finally, two short presentations are given by young physicists.

More information on these meetings (e.g. the calendar and programs of previous meetings) are available on this webpage: https://www.nathan-goldman-physics.com/bqi-meetings.

**10 January 2019**

*Quantum Systems under Drive: From Micro- to Macrophysics*

Sebastian Diehl (Univ. Cologne)

**7 February 2019**

*Quantum Atom Optics: Ocean & Universality in Quantum Dynamics*

Markus Oberthaler (Univ. of Heidelberg)

**14 March 2019**

*Exploring Flatland with cold atoms*

Jean Dalibard (Collège de France)

**4 April 2019**

*How the world looks like for a quantum particle? The covariance of physical laws in quantum reference frames*

Caslav Brukner (Univ. of Vienna)

**2 May 2019**

*Deciphering complex quantum systems*

Andreas Buchleitner (Univ. of Freiburg)

**28 November 2019** at Liège University

Seminar day on "Path-integral and semiclassical approaches"

# EPS-HEP CONFERENCE 2019

Ghent, 10-17 July 2019

The European Physical Society Conference on High Energy Physics (EPS-HEP) is one of the major international conferences that reviews the field every second year since 1971 and is organized by the High Energy and Particle Physics Division of the European Physical Society. The latest conferences in this series were held in Venice, Vienna, Stockholm, Grenoble, Krakow, Manchester, Lisbon and Aachen.

In 2019 the EPS-HEP conference took place in Ghent, Belgium from 10 to 17 July. The 2019 conference was organized by the Department of Physics and Astronomy of Ghent University in collaboration with Universiteit Antwerpen, Vrije Universiteit Brussel, Université Libre de Bruxelles and Université Catholique de Louvain.


## LOCAL ORGANIZING COMMITTEES

**Ghent University**

Tom Cornelis

Didar Dobur

Ianthe Michiels

Céline Moortgat

Dirk Ryckbosch

Daniele Trocino

Michael Tytgat - chair

Karel Van Acoleyen

Martina Vit

**Université Catholique de Louvain**

Eduardo Cortina Gil

Fabio Maltoni

**Universiteit Antwerpen**

Pierre Van Mechelen

Sarah Van Mierlo - secretary

**Vrije Universiteit Brussel**

Freya Blekman

Jorgen D'Hondt

Marleen Goeman - secretary

Steven Lowette

**Université Libre de Bruxelles**

Barbara Clerbaux - vice-chair

Gilles De Lentdecker

## TOPICS

- Astroparticle and Gravitational Waves
- Cosmology
- Dark Matter
- Neutrino Physics
- Heavy Ions Physics
- QCD and Hadronic Physics
- Top and Electroweak Physics
- Flavour Physics and CP Violation
- Higgs Physics
- Searches for New Physics
- Quantum Field and String Theory
- Detector R&D and Data Handling
- Accelerators for HEP
- Outreach, Education, and Diversity


# SCIENCE DAYS 2019

NOVEMBER 24 | 2019

# SCIENCE DAYS 2019

The Solvay Institutes participated to the Science Days of the Flemish Community more precisely to the Science Festival, organized on Sunday November 24, 2019.

The Solvay Institutes presented information about their history, mission and organization, illustrated with many pictures of past and recent activities on three posters (roll-ups).

On the other hand an introduction was given to the visitors about an intriguing concept/phenomenon in science transcending its different subdisciplines:

chirality: the remarkable fact that an object or process can be different from its mirror-image. The work by Louis Pasteur at the end of the 19$^{th}$ century gave a boost for the investigation of the "why and when" of chirality, which then first blossomed in chemistry. Later on it turned out that this concept also plays a fundamental role in describing processes in physics (e.g. at the level of elementary particles), in disentangling the activity of pharmaca, and even… in the definition of life is. Mathematicians have been actively looking for a quantitative description of this phenomenon.

The visitors' interest was raised by mirror experiments where they could convince themselves and their friends and family that they were not identical to their mirror image, surprising especially the younger "would-be" scientists. They were encouraged to manipulate themselves molecular models and came to the conclusion that also many of these models were not identical with their mirror image. This observation then leads in a natural way to the hypothesis that these molecules most probably will also undergo different "chemical" reactions. To test this hypothesis in this mini-scientific research program the visitors conducted an "odour" experiment where they could smell themselves that substances composed out of mirror – molecules do not always have the same odour. For the not so young-any-more visitors the link was then established with pharmacology by refreshing their minds on the Softenon tragedy in the early sixties of the previous century.

The Solvay exhibition stand received all day long many visitors enthusiastically interacting with Paul Geerlings (Emeritus Professor Chemistry at VUB and Vice-President of the Solvay Institutes), Tatiana Wöller (Assistant Chemistry at the VUB) and Eline Desmedt (researcher in de ALGC group of the VUB), and it was nice to see that children as well as adults got interested in this mini scientific excursion, and were, as we could witness, sometimes really amazed by these "tales and facts from the unexpected".

In conclusion the participation of the Solvay Institutes to the Science Days of the Flemish Community was a success. The Solvay Institutes want to acknowledge the Flemish Community for the financial support thy received for this activity.


Luisterpunt


The International Institutes
for Physics and Chemistry
founded by Ernest Solvay
... more than one century of scientific excellence!
Ernest Solvay

# VUB FELLOWSHIP

## NETWORKING EVENT

NOVEMBER 26 | 2019

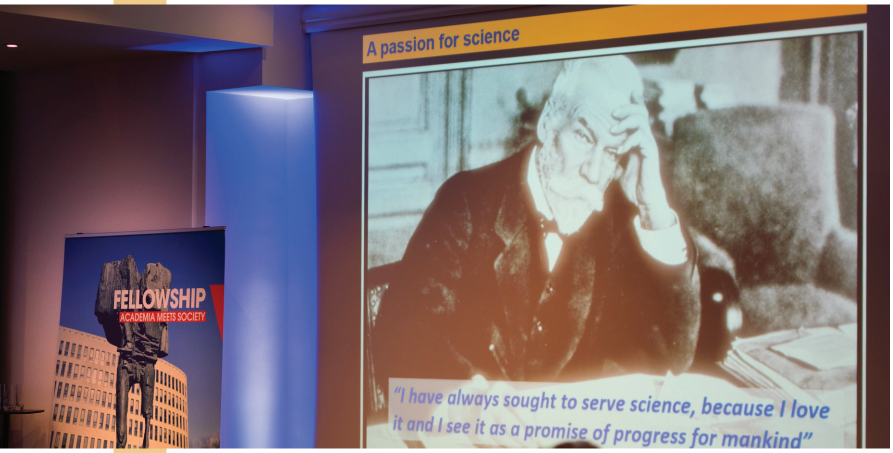
# VUB FELLOWSHIP
## NETWORKING EVENT

### MAISON ERNEST SOLVAY

26 November 2019

We are extremely pleased to have organized with the VUB an exclusive fellowship networking event at the Maison Ernest Solvay which was kindly made available by Solvay SA.

We assembled approximitavely 120 fellows of the VUB in the laboratory of Ernest Solvay. We were honored by the presence of the VUB Rector, Caroline Pauwels, various vice-rectors, the chairman of the Board of Directors, Eddy Van Gelder, and the Fellowship Coordinator Professor Hugo Thienpont:




> The aim of the VUB Fellowship program is to act as a platform where academics and the worlds of society and business meet. Here we can discuss joint challenges, exchange experiences, share good practices, and learn from one another for the benefit of research, academic education, and society in general. "VUB Fellow" is the highest grade of membership at our Alma Mater, a title bestowed upon unique personalities: top level business people, visionary decision makers, socially relevant personalities.

The International Solvay Institutes for Physics and Chemistry was pleased to present to such a prestigious assembly, the strong and lasting bond that exists between the VUB and the Solvay Institutes in the area of fundamental science.

Professor Sevrin and Professor Geerlings, both professors at the VUB and active in the Institutes, made presentations, explaining the impact of the Solvay conferences in physics and in chemistry since the beginning the 20th century. They also presented the activities that the institutes organize annually in support of the scientific community in Belgium and its universities. Most of the fellows were keen to understand the unique format that the Solvay conference has been using for over a hundred years and how effective it has been to inspire and promote creative collaboration between outstanding scientists. They were impressed by the number of scientific activities organized annually by the Institutes in support of fundamental science and available to the VUB student body. They also realized how important and lasting the bond between the Solvay Institutes and the Solvay company has been for scientific excellence in the Belgian university environment. The reality is that they were both founded by the same person that was incredibly passionate about science, Ernest Solvay. That is why it was absolutely fitting that the presentation occurred in the personal laboratory of Ernest Solvay.

At the end of the evening, we were able to share our passion for curiosity driven research with a group of highly motivated and interesting individuals. In that sense we had achieved our goal. Considering this, we are exploring the possibility of holding such an event with the ULB, a university with whom we equally share a long and collaborative history.

We wish to thank Isabelle Marneffe, Director of the VUB Foundation and Fellowship, Hanan Belaraj, Fellowship Coordinator for the help and assistance in making this possible.


## PROGRAMME


- Welcome by VUB Fellow Jean-Marie Solvay, Chairman of the Board of the International Solvay Institutes for Physics and Chemistry
- Introduction by professor Hugo Thienpont, Vicerector Innovation and Industrial Policy, VUB
- *"What the International Solvay Institutes bring to fundamental research and the VUB"*

  Keynote by Marc Henneaux, Director of the International Solvay Institutes, Paul Geerlings, Vice-President of the International Solvay Institutes, and Alexander Sevrin, deputy-Director of the International Solvay Institutes
- Introduction to the history of Maison Solvay by Nicolas Coupain, Corporate Heritage Manager Solvay
- Closing words by Rector Caroline Pauwels, VUB


FELLOWSHIP
ACADEMIA MEETS SOCIETY

# SEMINARS

# SEMINARS

The list below gives the joint inter-university weekly seminars co-organized by the Theoretical Particle Physics Group of the VUB, the Service de Physique Théorique and the Service de Physique Théorique et Mathématique, both of the ULB, the High Energy Physics and Relativistic Field Theory group of the KUL, the Groupe de Mécanique et Gravitations at UMons, and the International Solvay Institutes. It also gives the group seminars of the research team of the Director.

## JANUARY

*Holography meeting Leuven*

João Penedones (EPFL, Lausanne)
David Mateos (U of Barcelona)
Shira Chapman (U of Amsterdam)
Costis Papageorgakis (Queen Mary, London)

## FEBRUARY

*Entanglement and higher spins*
Per Sundell

*Gravitational dressing: soft charges, holography, and the quantum structure of gravity*
Steve Giddings (UCSB)

*From 3d dualities to 2d free field correlators and back*
Sara Pasquetti (Milan Bicocca U.)

## MARCH

*Little Strings, Long Strings, and Fuzzballs*
Emil Martinec (Chicago U., EFI)

*Fluids, holography and charges*
Marios Petropoulos (Ecole Polytechnique, CPHT)

*The off-shell renormalization of spontaneously broken effective gauge theories*
Andrea Quadri

*Black holes in N=4 Super-Yang-Mills*
Francesco Benini (SISSA, Trieste)

*Probing Black Hole Microstate Evolution with Networks and Random Walks*
Anthony Charles (KU Leuven)

*How to Build a Wormhole*
Ben Freivogel (U. of Amsterdam)

*Energy level splitting for weakly interacting bosons in a harmonic trap*
Surbhi Khetrapal

## APRIL

*Cosmological imprints of dark matter*
Laura Lopez Honorez

*Asymptotic charges in gravity*
Mahdi Godazgar

*Geometry and physics of Quantum Hall states*
Semyon Klevtsov

Stefan Fredenhagen

# MAY

*Properties of the exact partition function of supersymmetric gauge theories with massive matter*
Jorge Russo

*Partially massless fields and supersymmetry*
Sebastian Garcia-Saenz

*Genus one string amplitudes from CFT*
Agnese Bissi

*On Lower-Dimensional Gravity*
Jan Troost

*Scattering on curved backgrounds*
Tim Adamo

*Large Nf expansion, dualities and symmetry breaking in 2+1 dimensional gauge theories.*
Sergio Benvenuti

# JUNE

*Integrability on the string worldsheet*
Alessandro Sfondrini

*New techniques in quantum gravity*
Marc Geiller (Lyon, ENS)

*Probing Microstate Geometries*
Ruben Monten (IPhT, Saclay)

*Chern-Weil theorem and boundary terms in gravity actions*
Nelson Merino

*Hypergravity*
Javier Matulich

*'t Hooft anomalies and supersymmetric partition functions*
Cyril Closset (Oxford U.)

# AUGUST

*Towards surface charges in spacetimes with curvature and torsion*
Jens Boos

# SEPTEMBER

*Bondi gauge and charges of (A)dS_4*
Aaron Poole (Southhampton U.)

# OCTOBER

*Holography and Flat Space*
Chethan Krishnan

*Areas and entropies in BFSS/gravity duality*
Tarek Anous (UvA)

*Thoughts on Black Holes and Higher Derivatives*
Gary Gibbons (Cambridge)

*The Higgs Mechanism and Hasse diagrams*
Antoine Bourget

*Determinism and Quantum Theory inside Black Holes*
Stefan Hollands

*Weyl Symmetry in Holography*
Luca Ciambelli (ULB)

*Cosmic footballs from superrotations*
Will Donnely

Alex Arvanitakis

## NOVEMBER

*Black hole interiors and modular inclusions*
Ro Jefferson

*The holographic QCD axion*
Aldo Cotrone

*On Vacuum Stability with Broken Supersymmetry*
Augusto Sagnotti

*Holographic Entanglement Entropy and Kounterterms*
Rodrigo Olea

*Localization of the action in AdS/CFT*
Pietro Benetti Genolini

Tristan McLoughlin

## DECEMBER

*Vacuum stability without Supersymmetry: Brane dynamics, bubbles and holography*
Ivano Basile

*Kähler moduli stabilization from ten dimensions*
Ander Retolaza

*Modularity of 3-manifold invariants*
Francesca Ferrari

*Quasi-local conserved charges in general relativity*
Henk Bart

*Generalised global symmetries and magnetohydrodynamics*
Akash Jain

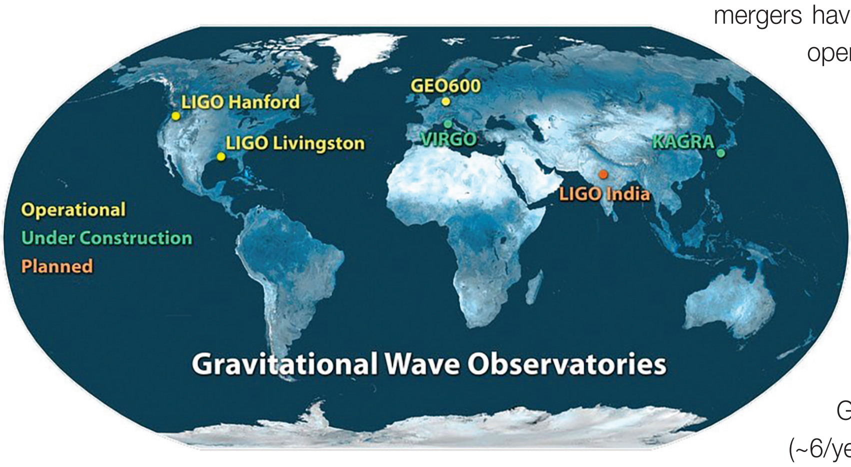
*The physics of jamming: a journey from marble pebbles toward scaling invariant field theory*
Giorgio Parisi (Università La Sapienza, Roma, Italy)

*Bottom-up construction of 4d N=2 SCFTs*
Wolfger Peelaers

*Bulk entanglement entropy for photons and gravitons in AdS_3/CFT_2*
Alexandre Belin (CERN)

## GRAVITATIONAL WAVE SEMINARS

The discovery of gravitational waves in 2016 has opened a new era in the exploration of our Universe. At present, several transient gravitational wave signals associated to binary system mergers have been reported by LIGO/VIRGO. An interesting open question is if the Universe is also permeated by a stochastic gravitational wave background, that can be of astrophysical or cosmological origin.




To actively encourage Belgian research on Gravitational Wave Physics and other astrophysical observations that can make contact with fundamental physics, GW meetings and seminars are organized.

GW MEETINGS: a regular set of half-day meetings (~6/year). A GW meeting typically starts in the afternoon with a seminar by an international expert, followed by a talk by a local researcher (local = working in Belgium-affiliated group). As the main aim is to stimulate the local community, there will be ample time for breaks and discussions over coffee and drinks.

## MARCH

*The motion of small objects around spinning black holes*
Maarten van de Meent (MPI Potsdam)

*Solar mass black holes and dark matter*
Peter Tinyakov (ULB)

## MAY

*An analytic approach to non-linear cosmic structure formation*
Matthias Bartelmann (Heidelberg)

*Cosmology with gravitational wave standard sirens: current results and future prospectives*
Nicola Tamanini (AEI Potsdam)

*Accelerated expansion from decaying AdS*
Marjorie Schillo (Uppsala)

## SEPTEMBER

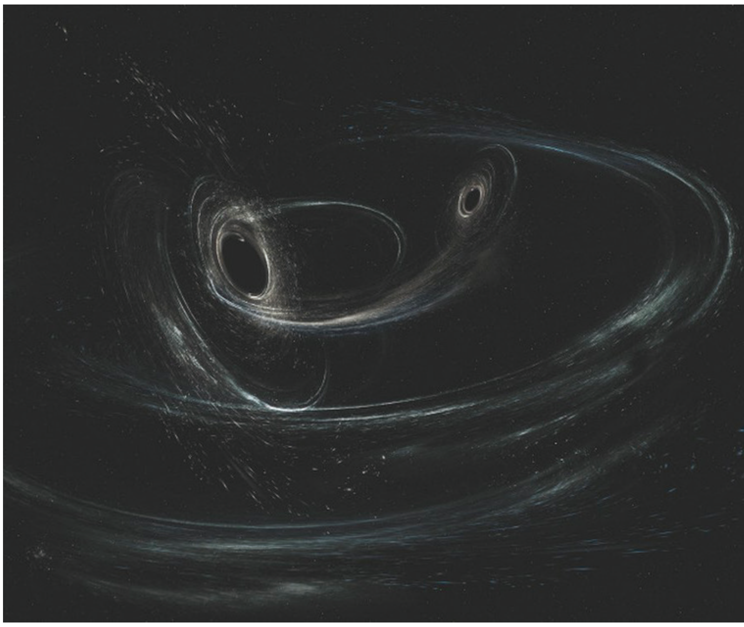
*New prospects in numerical relativity*
Helvi Witek (King's College, London)

*Probing the internal structure of compact objects with gravitational waves from comparable-mass binary inspirals*
Tanja Hinderer (University of Amsterdam)

## OCTOBER

*Gravitational-wave Astrophysics: LIGO/Virgo BH-BH/BH-NS/NS-NS mergers*
Chris Belczynski (Copernicus Center, Warsaw, Poland)

*Primordial black hole predictions for black hole merger detections in LIGO/Virgo*
Sébastien Clesse (CURL, UCLouvain)



## NOVEMBER

Stochastic GW day

*The quest for the Gravitational-Wave Stochastic Background with Advanced LIGO and Advanced Virgot*
Tania Regimbau (LAPP Annecy)

*Electroweak baryogenesis*
Thomas Konstandin (DESY)

*Gravitational Waves from the Electroweak Phase Transition*
Jose Miguel No (Madrid University)

*Connection to Dark Matter*
Iason Baldes (ULB)


# RESEARCH


## Exploring New Frontiers

# CONTENTS

# RESEARCH ON GRAVITATION, STRING THEORY AND COSMOLOGY

Groups of Professors Marc Henneaux | ULB and Alexander Sevrin | VUB

## RESEARCHERS

### Faculty Members

Riccardo Argurio | ULB
Vijay Balasubramanian | VUB
Glenn Barnich | ULB
Chris Blair | VUB
Andrès Collinucci | ULB
Geoffrey Compère | ULB
Ben Craps | VUB
Nathalie Deruelle | ULB & CNRS
Stéphane Detournay | ULB
François Englert | ULB, Honorary Member of the Institutes
Oleg Evnin | VUB
Frank Ferrari | ULB
Marc Henneaux | ULB
Axel Kleinschmidt | Max-Planck-Institute, Potsdam
Laura Lopez Honorez | VUB
Alberto Mariotti | VUB
Alexander Sevrin | VUB
Daniel Thompson | VUB

### Postdoctoral Researchers

Ahmed Aqeel | VUB
Alexandros Arvanitakis | VUB
Martin Bies | ULB
Luca Ciambelli | ULB
Oscar Fuentealba | ULB
Eduardo García-Valdecasas | ULB
Adolfo Guarino | ULB
Surbhi Khetrapal | VUB
Yegor Korovin | ULB
Victor Lekeu | ULB & Imperial College, London
Sucheta Majumdar | ULB
Javier Matulich | ULB
Wout Merbis | ULB
Saereh Najjari | VUB
Turmoli Neogi | ULB
Stefan Prohazka | ULB
Charles Rabideau | VUB
Arash Ranjbar | ULB
Max Riegler | ULB
Ali Seraj | ULB
Charlotte Sleight | ULB
Hongbao Zhang | VUB

### Doctoral Researchers

Ankit Aggarwal | ULB
Martin Bonte | ULB
Jonathan Crabbé | ULB
Marine De Clerck | VUB
Adrien Druart | ULB
Adrien Fiorucci | ULB
Philip Hacker | VUB
Sam Junius | VUB
Lorenzo Küchler | ULB
Yan Liu | ULB
Daniel Naegels | ULB
Pierluigi Niro | ULB/VUB
Antoine Pasternak | ULB
Romain Ruzziconi | ULB
Colin Sterckx | ULB
Guillaume Valette | ULB
Quentin Vandermiers | ULB
Sofia Zhidkova | VUB

# RESEARCH SUMMARY

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).

We have continued our research along the general directions outlined above. This has led to 114 published papers and preprints submitted for publication. These are listed on pages 144 - 149. 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 Solvay 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.

# MARINA SOLVAY FELLOWSHIP

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.

### List of Marina Solvay fellows

Waldemar Schulgin (2012-2014)
David Tempo (2015)
Jelle Hartong (2016)
Adolfo Guarino (2017)
Charlotte Sleight (2018)

**2019 Marina Solvay Fellow - Sucheta Majumdar** I Postdoctoral Researcher I ULB

Sucheta Majumdar got her PhD degree at the IISER in Pune (India) in 2018 before joining the group of the Director at ULB. Her work deals with hidden symmetries in pure gravity, in supergravity and in extended supergravity models. More recently, she turned to the question of asymptotic symmetries in gravity in the asymptotically flat space context, where infinite dimensional groups also appear.

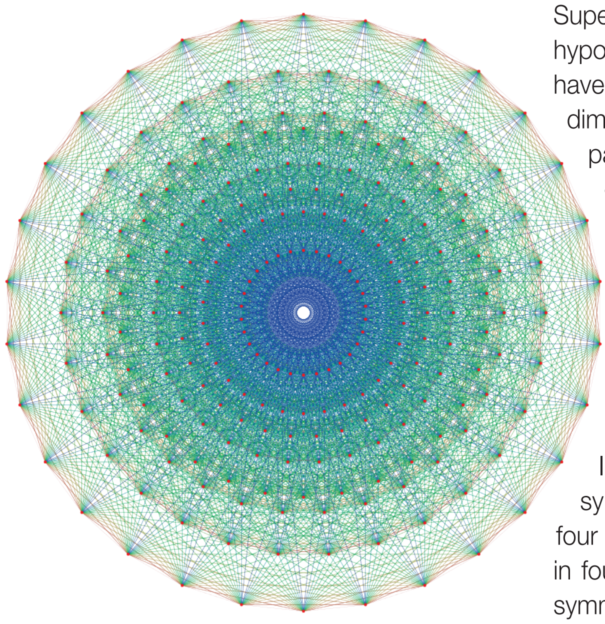
### Looking through the lens of symmetries

The art of formulating consistent physical theories relies on some underlying principles. These include locality that rules out action-at-a-distance, unitarity that ensure the probabilities add up to one, symmetries that account for invariance of physical systems under certain transformations, to name a few. Among these key elements, symmetries turn out to be a preferred one in a theorist's toolkit, as they assist in shaping the theories methodically. By virtue of the celebrated Noether's theorem, symmetries lead to conservation laws, which also put constraints on the form of the action functional of the theory. The action functional is a mathematical expression from which one can compute equations of motion that govern the dynamics, scattering amplitudes that measure the probability of occurrence of physical processes, etc. Symmetries often form a Lie group in mathematics, which offers an incredible handle on how to further shape the theories.

Symmetries of the spacetime, for instance, the well-known Lorentz and Poincaré group, are usually accompanied by other classes of symmetries that act on the internal space of the physical fields. Gauge symmetries are an important class of such internal symmetries, which deal with the redundancies in the description of a physical theory. Often referred to as gauge freedom, this symmetry allows one to study the same theory from different angles. The framework of quantum field theory, which is the foundation of the Standard model of particle physics, beautifully intertwines both gauge symmetries and spacetime symmetries. The concept of coordinate invariance in gravity gives rise to the elegant theory of general relativity, that nicely knits Poincaré symmetry and gauge symmetry into the notion of diffeomorphism invariance.

The last decade has witnessed some remarkable strides in our pursuit to unravel the mysteries of the universe with the discovery of the Brout-Englert-Higgs boson at the LHC, the experimental detection of gravitational waves by the LIGO and the first ever image of a black hole captured by the Event Horizon telescope. Nevertheless, our current understanding of the fundamental interactions in nature stands incomplete, for we still lack a single unified theory that can put together these recent findings under the same umbrella. Any attempts to reconcile general relativity with the laws of quantum mechanics within the framework of quantum field theory are typically met with ultraviolet divergences. In this regard symmetries play a central role, since divergence cancellations in quantum field theories can most often be traced back to a symmetry in the theory. Therefore, in order to understand the quantum nature of gravity and fix the divergences, a precise knowledge of all its symmetries is indispensable.

The study of symmetries in theoretical physics is much alike solving a giant jigsaw puzzle. To solve a puzzle to completion, sometimes it helps to identify a pattern among the different pieces, while for some parts one must carefully examine each edge of the smaller pieces to understand how they fit together to form the big picture. In the same spirit, in order to fully appreciate a symmetry, it is often worthwhile to study it from various angles. The theme of my current research, thus, focuses on the study of certain classes of symmetries in gravity and gauge theories under different formulations or choices of gauge.



*The exceptional $E_8$: a 2-D projection of the root diagram of $E_8$ in mathematics*

### Light-cone gauge: the choice of time

In 1949, Dirac showed that for relativistic theories, any direction within the light-cone can be treated as the evolution parameter or the time coordinate, including the null direction $x^+$ along which light travels. In these coordinates, called the light-cone frame, one can choose the gauge such that the theories contain only the physical states, as all extra degrees of freedom can be eliminated using some constraint equations. As a consequence, symmetries in the light-cone formulation are realized non-linearly on the physical fields in a perturbative expansion. This provides us with a unique first-principles approach for constructing interacting theories from the knowledge of symmetries alone, by demanding closure of the symmetry algebra of the theory. In an earlier work, we applied this framework to Yang-Mills theory to derive four-point interaction vertices and are currently applying the same technique to spin two and higher, in order to see if it is possible to construct a consistent higher spin action on a flat (or a curved) spacetime.

Supergravity theories, based on supersymmetry – a hypothetical symmetry between bosons and fermions, have been known to exhibit rich hidden symmetries upon dimensional reduction from their higher-dimensional parent theories. These symmetries form Lie groups of the exceptional type, for example, $E_6$, $E_7$, ..., $E_{10}$ and are, hence, affectionately called exceptional symmetries. In the recent years, these symmetries have been realized in the parent theory prior to dimensional reduction suggesting their existence already in the higher-dimensional theories. The light- cone approach has, in fact, proved to be quite fruitful in this regard, as my collaborators and I have been able to find strong indications for an $E_7$ symmetry in eleven dimensions and an $E_8$ symmetry in four dimensions, while these symmetries originally occur in four and three dimensions, respectively. Since these symmetries are intimately connected to string theory, the study of their origin in the eleven-dimensional theory might also offer new insights into M-theory, whose actual structure eludes our understanding.

### Duality symmetries: locality versus non- locality

Originally encountered in the theory of electromagnetism, duality symmetries are a delightful surprise in theoretical physics. The electromagnetic duality symmetry refers to the invariance of vacuum Maxwell's equations under the exchange of electric and magnetic fields. Its extension to Maxwell's equations in presence of sources hints at the intriguing possibility of the existence of magnetic monopoles in nature. The duality symmetry in gravity leaves the Einstein's equation invariant under the rotation of some components of the curvature tensor into each other. Duality symmetries occur in abundance in supergravity theories in the context of exceptional symmetries. Since these symmetries occur at the level of equations of motion, it is not so straightforward to promote them to the level of the action. As a matter of fact, duality-invariant actions for interacting theories are precluded by a plethora of no-go theorems that rule out such interactions on the grounds of Lorentz covariance and locality. For free theories though, the prepotential formalism has proved to be quite successful for deriving duality-invariant actions.

In a recent work, we formulated an interacting action for gravity in four dimensions that is invariant under Ehlers symmetry, a symmetry that traditionally appears only after reduction to three dimensions. The Ehlers symmetry contains the duality symmetry of gravity as a subgroup, such that the action so obtained is manifestly symmetric under duality rotations. The price to pay, however, is that the formulation is Hamiltonian, i.e. first-order in time derivative, not Lorentz covariant and non-local in the space coordinates. In light of these results, I am trying to explore the notion of spatial non-locality in the prepotential formalism and the framework of BRST formalism for gauge theories, with the aim to understand and hopefully circumvent these no-go theorems.

### Asymptotic symmetries: how to approach infinity

As the name suggests, these are the spacetime symmetries that arise when one approaches asymptotic infinity. One may move along a spacelike direction to go to spatial infinity or along a null direction and thus reach null infinity. For spacetimes that are asymptotically flat at null infinity, the asymptotic symmetry, known as the BMS group, was found out to be an infinite-dimensional enhancement to the naïvely expected Poincaré group. Similar studies have been conducted for other gauge theories like electrodynamics, Einstein-Maxwell theory, etc. where such symmetry enhancements are seen. There has been a renewed interest in the study of asymptotic symmetries following a recent body of work, wherein these symmetries have been connected to soft theorems for gauge theories.

The study of asymptotic symmetries is very sensitive to the boundary conditions imposed on the fields at infinity. Early attempts to recover the BMS group at spatial infinity were met with failure, as the required choice of boundary conditions would lead to ill-defined symmetry generators and conserved charges. This gap in our knowledge was bridged in a recent work by Marc Henneaux and Cedric Troessaert, in which the BMS group was obtained at spatial infinity by virtue of a meticulously crafted set of boundary conditions that respects the notion of canonical conserved charges. In a current project with Oscar Fuentealba, Marc Henneaux, Javier Matulich at ULB, we are trying to extend this analysis to higher-spin gauge fields to understand how the interplay of higher-spin symmetry with Poincaré symmetry brings about interesting asymptotic dynamics at spatial infinity.

These few examples illustrate how the study of symmetries from different vantage points might offer a better picture of the nature of spacetime and eventually help us inch forward in our search for a quantum theory of gravity.

# RESEARCH INTERESTS OF SOME POSTDOCTORAL RESEARCHERS

**Ali Seraj** I Postdoctoral Researcher I ULB

### Symmetries in gravitational waves

In the past 5 years, fascinating discoveries have been achieved which highly affect our understanding of the universe. Among those are the first detection of gravitational waves in September 2015 by LIGO collaboration, exactly one century after its prediction by Einstein. Now, there are more than 10 detections of gravitational waves from different sources.

Why is gravitational waves important? Because it is a new messenger using which we can "see" things we were not able to see using electromagnetic waves. Indeed it opens a new window on the universe. What is the source of gravitational wave? Very much like electromagnetism, gravitational waves are generated by accelerating objects. But because of the very weak nature of gravity (compared to electromagnetism), the objects should be very heavy and very dense in order to produce a sufficiently powerful wave that can be detected by our detectors. And the best candidates with these properties are "black holes" and "neutron stars". Two black holes orbiting each other with high frequency emit gravitational waves and loose energy until they merge into a single black hole. During this process they can lose a tremendous amount of energy, equivalent to the sun transferring all its mass to energy through nuclear reactions three times!

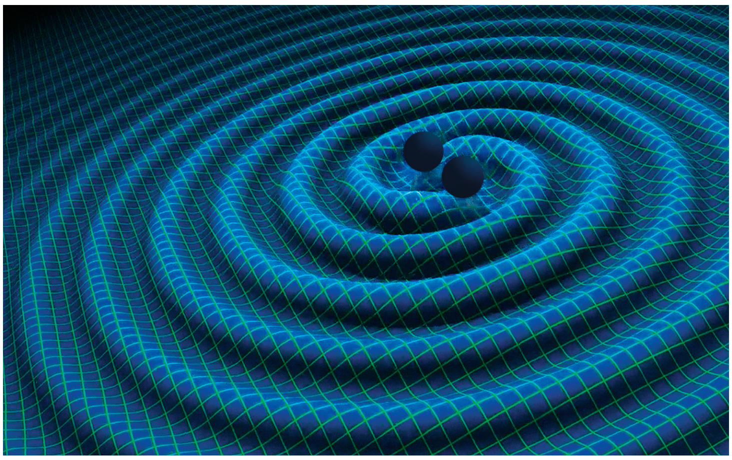


*Figure 1. Binary black holes emitting gravitational waves.*
*Credit: LIGO scientific*

Due to the nonlinear nature of Einstein equations that govern the gravitational dynamics, the analysis of wave generation in this theory is way more complicated than in electrodynamics. For extraction of data from the observed gravitational waves, very accurate modelling of the waveform is needed. Therefore, different analytic approximation methods as well as numerical methods have been developed in the past decades.

Symmetries and conservation laws are of great importance in the study of dynamical systems, particularly when the evolution of the system is highly nonlinear. According to a theorem by Emmy Noether (1918), each symmetry leads to a constant of motion which can be used to constrain the dynamics of system. The well-known examples of this notion are the energy, momentum and angular momentum of isolated systems.

For Einstein theory, the analysis of symmetries is more involved. It turns out that the relevant symmetries for an infinite dimensional group known as the BMS group. While found during the study of gravitational waves in the 60's, interesting relations have been found with the low energy behavior of the gravitational scattering matrix as well as the memory effects.My research in the past year focused on the application of BMS symmetries and their associated conservation laws in constraining the dynamics of radiating systems such as black hole binaries. The result is published in a paper in collaboration with Prof. Geoffrey Compère and Dr. Roberto Oliveri [1].

In more technical words, we find a "flux balance equation" for each of the generalized BMS symmetries expanded in symmetric trace-free harmonics. The flux of each BMS charge multipole is then written in terms of radiative multipole moments. We show that these equations provide an exact extension of Einstein quadrupole formula as well as other Poincare flux balance laws. Moreover, our approach allows to introduce infinitely many novel balance laws that have not been studied before.

Special attention is paid to the post-Newtonian (PN) order of each flux balance law. We know that the PN order of energy and angular momentum balance laws are 2.5 (which means that they are proportional to $1/c^5$) and have the most important role in the study of binary systems. In this work we show that there are other flux balance equations that appear at 2.5 PN order. Accordingly, they might have potential application in the study of binary systems.

Gravitational waves are also important in our understanding of fundamental aspects of the theory of General Relativity and theory of black holes. Still there are open problems regarding the thermodynamic properties of black holes as well as the final state of matter after falling into a black hole.

*[1] G. Compère, R. Oliveri, and A. Seraj,* The Poincaré and BMS Flux-Balance Laws with Application to Binary Systems *(2019).*

*[2] E. S. Kutluk, A. Seraj, and D. Van Den Bleeken, JHEP01 184 (2020).*

*[3] A. Seraj and D. Van Den Bleeken, J. High Energy Phys.* ***2017****, 1 (2017).*

### Vacua of General Relativity

In a different but related context, I collaborated with Prof. Dieter Van den Bleeken and Dr. Emine Seyma Kutluk. [2] The aim of this project was to study more thoroughly the vacua of Einstein theory in the presence of boundaries.

Vacuum is subtle notion in Einstein theory due to the presence of "diffemorphisms", the symmetries of General Relativity. A classical vacuum is defined as a configuration in the local minima of the potential. In a typical theory the vacuum is unique, but as soon as there is a symmetry that does not change the energy while acting nontrivially on the state of the system, the system will have a degenerate set of vacua. This is known as "spontaneous symmetry breaking". The goal of this project was to study more thoroughly the space of vacua of classical Einstein theory in the presence of boundaries. We implemented the Manton (adiabatic) approximation, which is a well-known technique in the context of solitonic moduli spaces. The basic idea is that in the presence of degenerate vacua, the low energy excitation of the system leads to an adiabatic motion along the vacua. We consider the space of all vacuum configurations diffeomorphic to flat space confined with a set of boundaries. It turns out that Einstein equations do not allow for motion along pure gauge directions (those vanishing at the boundaries), while they allow for motion on "large gauge" directions (that are finite at the boundaries). In this way, we identify the space of physical vacua of the theory. Now the adiabatic analysis allows to probe important properties of the space of vacua. The result is that the space of vacua is an infinite dimensional homogeneous space equipped with a pseudo-Riemannian metric, which we specify. Moreover low energy solutions of the Einstein equations correspond to null geodesics on the space of physical vacua.

**Wout Merbis** I Postdoctoral Researcher I ULB

## Gravity and quantum mechanics: an unruly marriage

The fundamental laws of nature are quantum mechanical, with one obvious exception: gravity. The interaction of fundamental particles are to incredible precision described by the standard model of particle physics. This is a specific example within a framework of theories called quantum field theory (QFT). The phenomenological success of the standard model is, however, contrasted by our failure of understanding gravity as a quantum field theory; naively applying the rules of QFT to gravity give nonsensical answers.

Still, some of the deepest and most profound questions about the nature of our reality ultimately rely on a quantum theory of gravity. These include the very instant of the creation of the universe: the Big Bang, and the center of black holes, where our current understanding of the laws of gravity breaks down. To correctly explain these phenomena, and to obtain a more comprehensive understanding of Nature, we need to formulate a theory of quantum gravity.

A major obstacle in the search for this theory is the fact that we cannot rely directly on experimental data. The energies needed to probe these scales are simply too high to be accessible in any laboratory. While experiments, such as high-energy particle colliders, have been able to decisively test which QFT is responsible for the fundamental interactions of particles, there is no direct experiment that is able to rule out possible candidate theories of quantum gravity. For this we are surrendered only to the mathematical consistency of the theory itself, combined with indirect evidence from cosmology, and the favorite pass-time of the theoretical physicist: thought experiments.

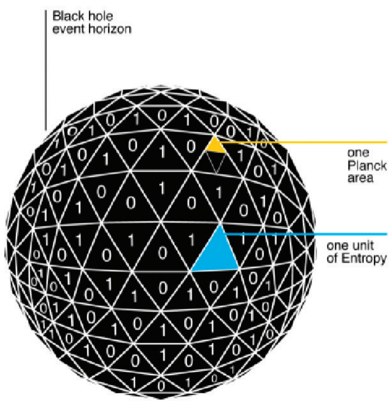



*Figure:*
*The black hole has entropy proportional to the area of its event horizon.*

Stephan Hawking had famously proposed one such thought experiment alluding to black holes. He imagined a black hole in empty space. From the rules of quantum mechanics, we know that the vacuum is not completely empty. In fact, pairs of particles are being created spontaneously all the time, as long as they are annihilated shortly after. The presence of a black hole complicates this process. Not all pairs can annihilate again, as some particles may fall into the black hole and can never come back out. The remaining partner can escape the grasp of the black hole and from a distance it will look as if the black hole has emitted this particle. From this simple thought experiment, combining black holes with quantum theory, Hawking managed to show that black holes in fact are not completely black, but they radiate quantum particles!

As anything that radiates, black holes must therefore also have a temperature and entropy. Hawking and his collaborators even managed to show that black holes satisfy all the usual laws of thermodynamics, only when the entropy of the black hole is identified with the area of its horizon. It turns out that the relation between gravity and thermodynamics is not limited to black hole physics, but it seems to be more generic. The key question is, what is gravity the thermodynamical limit of?

One is used to study thermodynamics for different states of matter, which are composed out of atoms or molecules. For instance, a gas is made out of molecules floating and wiggling around. The temperature is not a property inherent to the individual molecules making up the gas, but rather a collective entity which arises from the statistics of many particles. The entropy of the gas measures how many different configurations of molecules (microstates) give rise to a gas with the same thermodynamic properties. What are then the corresponding microstates that the black hole entropy counts?

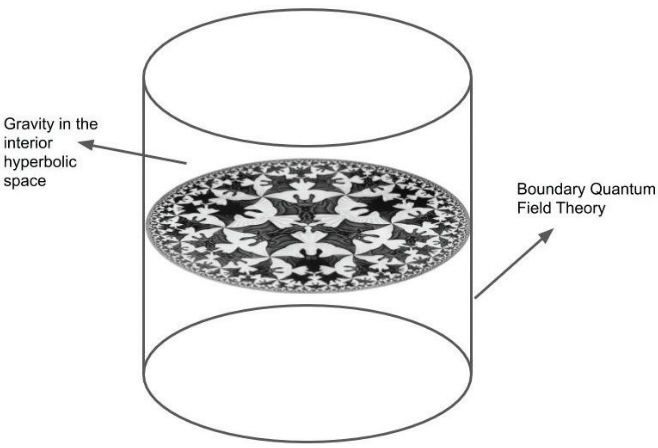



*Figure: Holography states that a theory of quantum gravity in the interior of the cylinder is equivalent to a QFT living on the boundary.*

*[1] M. Henneaux, W. Merbis, A. Ranjbar, Asymptotic dynamics of AdS3 gravity with two asymptotic regions, JHEP 03 (2020) 064*

*[2] W. Merbis and M. Riegler, Geometric actions and flat space holography, JHEP 02 (2020) 125*

*[3] S. Detournay, W. Merbis, G.S. Ng and R. Wutte Warped Flatland (2020)*

### The universe as a hologram

A major advance in identifying the microstates responsible for gravity as a thermodynamic theory is called holography. Proposed by Susskind and 't Hooft, it was born out of the observation that black holes have entropy proportional to the area of its horizon, whereas most known forms of matter have an entropy proportional to its volume. Could it be that the microstates describing the black hole entropy are (analogues of) molecules in a lower dimensional theory? The area of a surface is then a volume of a lower dimensional space! A concrete example of this was worked out by Maldecena and goes by the name of the AdS/CFT correspondence. It posits that a theory of quantum gravity in spacetimes with negative curvature in five dimensions is in fact the same as a special type of QFT in four dimension. This four dimensional theory has enhanced symmetries (it looks the same at all length scales) and is called a conformal field theory (CFT).

Since the advent of the AdS/CFT correspondence, much effort has been devoted to apply the ideas of holography to other setups or in different numbers of dimensions. My research has been focused on lower dimensional models of holography, which are technically easier to handle, but still contain much of the relevant physics of our four dimensional world. We have been studying the connection between gravity in three spacetime dimensions and two-dimensional conformal field theories. It turns out that for three dimensional gravity, the dynamics is entirely dominated by boundary conditions and the theory can be reduced to a CFT on the asymptotic boundary. With Marc Henneaux and Arash Ranjbar we have studied this reduction for the cases relevant to the three dimensional black hole. With Max Riegler we have addressed these issues for spacetimes which are asymptotically flat in three dimensions. We were able to link three dimensional gravity to a two-dimensional field theory which has a close connection to a mathematical theory of infinite dimensional symmetry groups.

Finally, the holographic correspondence between gravity and quantum field theories can be used to account for the entropy of black holes. This was shown in a seminal work by Strominger in the case of the three dimensional black hole. He showed that the entropy computed from the asymptotic density of states in a two dimensional conformal field theory exactly matches the entropy of the three dimensional black hole. Together with Stéphane Detournay, Gim Seng Ng and Raphaela Wutte, we were able to show that this matching also holds for more exotic spacetimes, which are dual to theories without conformal symmetries, but with so-called warped conformal symmetries. All these examples provide indications that holography is more general than AdS/CFT and can be applied to other cases as well.

**Alex S. Arvanitakis** | Postdoctoral Researcher | VUB

String theory is often described, especially in popular articles, using adjectives such as “beautiful”, “elegant” and “rich”. These are usually quickly followed by “intricate”, “complex”, and, in less charitable treatments, “baroque”. It is indeed fair to say string theory is one of the most complicated theories of physics ever considered; however, it is also the most credible candidate for a unifying theory of physics. The rationale for my research in the broadest possible terms is that structures found inside string theory are therefore likely to be universal: the connections and commonalities that are visible in a stringy scenario in the face of the intricacies demanded by the remarkable internal coherence of string theory are likely to have been there all along also in simpler systems, hiding in plain sight.

To see why such generalisations away from string theory can be fruitful, we need to have some idea of what string theory is. String theory studies the implications of its own most basic postulate: that the fundamental building blocks of matter and spacetime are quantum strings. These strings are broadly analogous to elastic bands: they can stretch — at a cost of energy — and they can vibrate. Such vibrations resolve into a superposition of distinct harmonics, much like the vibrations of the strings of a cello do. However, the harmonics of a fundamental string correspond not to musical notes, but to elementary particles. The particle spectrum predicted is uniquely specified by the type of string under consideration, and mathematical consistency singles out exactly five types of fundamental string, all of which naturally live in ten spacetime dimensions (nine of space and one of time).

That would be but a novelty, were it not for the fact that all five string theories contain a graviton inside their particle spectrum: the hypothetical particle that mediates the force of gravity, whose wave avatar in the sense of wave-particle duality of quantum mechanics is a gravitational wave (first directly observed by the LIGO and Virgo collaborations in 2015). String theory therefore is a consistent quantum-mechanical theory describing the interactions of the graviton, thereby bridging the famous chasm separating quantum mechanics and general relativity.

I have so far been referring to “string theories” as well as a single “string theory” somewhat inconsistently. The reason is that all five types of string theory in ten dimensions are related by dualities, meaning they describe equivalent physics. One example is T-duality: when one spatial dimension is periodic of length l, the T-dual theory will involve a circle of length $\propto \ell^{-1}$; concretely, the momentum quanta of a string along the original circle are swapped for the winding of the dual string along the dual circle.

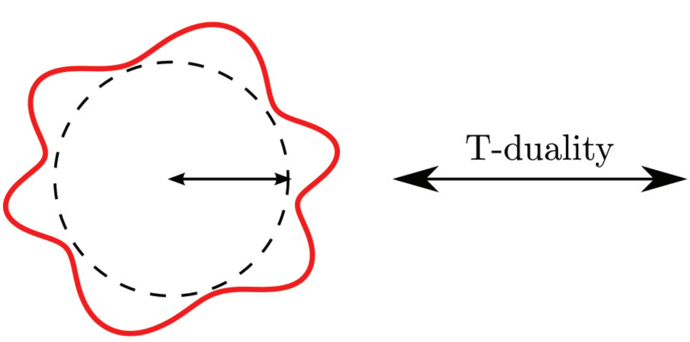



*Figure 1: Artist’s conception of a duality: T-duality states that the string (solid lines) wound twice around the small circle (dashed lines) on the right is physically equivalent to the string moving around the bigger circle to the left. In string theory, length (of circles) does not matter!*

My research revolves around higher algebraic and geometric structures in string theory, the study of dualities, and applications of these closely-related ideas. “Higher” has a very precise meaning in mathematical circles (referring to the esoteric discipline of “higher category theory”); in the context of string theory it almost always means “irreducibly stringy”. For example, the string naturally houses a “higher” analogue of electromagnetism, where the “higher electric charge” is simply the winding of the string itself. This illustrates a general pattern: higher structures can naturally be discovered in fundamentally stringy physics; remarkably, some of them are robust enough to generalise away from string theory too.

As an example: it is well-known since Murray Gell-Mann’s 1961 “eightfold way” classification of the zoo of hadrons emerging from particle collisions at the time, that symmetries in particle physics realise the mathematical idea of a Lie algebra. When calculating string scattering amplitudes — what a particle collider large enough to resolve stringy physics would see — physicists discovered the higher generalisation now known as a “homotopy Lie algebra”, that is large enough to accommodate the symmetries of string theory. Shortly before I joined VUB I was able to show that these higher symmetries are a universal feature of quantum fields, hiding in plain sight. They naturally lead to efficient calculational techniques relevant for real world physics.

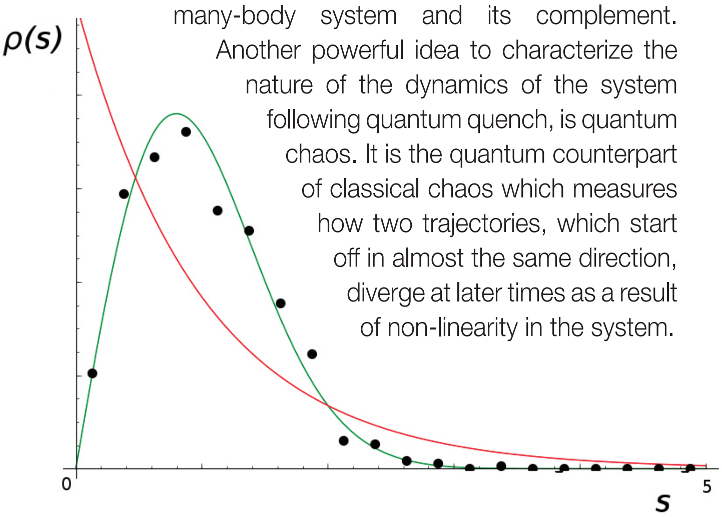
Another research project illustrative of the general thrust of my research programme is an investigation of black hole physics and T-duality (with Chris Blair of VUB). Since T-duality modifies the geometry of spacetime, it is natural to wonder about the fate of a black hole geometry under this transformation. By investigating black hole physics in a novel and powerful geometry — known as “double field theory” — where dualities are interwoven with the structure of spacetime, we were able to show that while a black hole geometry will transform under T-duality, it will always go to a physically equivalent black hole: the mass, temperature, and entropy will be the same.

**Surbhi Khetrapal** | Postdoctoral Researcher | VUB

My research interest lies in studying time dependence and chaotic properties in out-of-equilibrium quantum systems. In recent times research has been focused towards understanding the full time dependence of dynamical systems. This is motivated by experiments which have been able to track the evolution of quantum states in out-of-equilibrium systems. This has been achieved especially in the field of cold atoms, where gases of atoms can be successfully trapped in optical lattices formed by the interference of two lasers with different frequencies. It is possible to track the evolution of the quantum system in real time in these experiments.

In my research I study dynamical systems undergoing quantum quench. A quantum quench is a non-adiabatic change of certain parameters of the system such as temperature, energy density, external field like magnetic field or a parameter in the Hamiltonian like mass or coupling constant. Quenches provide a simple way to drive a system away from equilibrium while still generating rich dynamics and a wide range of phenomena.

We use observables from quantum information to study the time dependence of a dynamical system following quantum quench. One such observable is entanglement entropy, which measures the degree of quantum entanglement between a sub-system of a quantum many-body system and its complement. Another powerful idea to characterize the nature of the dynamics of the system following quantum quench, is quantum chaos. It is the quantum counterpart of classical chaos which measures how two trajectories, which start off in almost the same direction, diverge at later times as a result of non-linearity in the system.




### Time dependence following quench in Conformal field theory

A conformal field theory is a quantum field theory invariant under conformal transformation, which means that the physics of the theory looks the same at all length scales. Two types of quantum quenches have been studied in conformal field theories: a global quench is when a system is evolved from an initial quantum state which is globally different from the energy eigenstate of the Hamiltonian; a local quench is generated by a localized change in the initial quantum state or density matrix so that it departs from the ground state only locally.

In my research I have computed holographically the analytic formula for time dependent retarded Green function following global quench in conformal field theory, and studied its thermalization. I have studied universal correction to time dependent entanglement entropy following local quantum quench in two dimensional conformal field theory. In this theory, we have also studied the Lyapunov exponent, a quantity which dictates how fast information scrambles in a chaotic theory. A bound on the Lyapunov exponent was proposed for holographic conformal field theories. In my research we have verified that this bound is satisfied even when the holographic conformal field theory carries a sufficiently small higher spin charge such that the theory remains unitary.

### Quantum chaos in a quantum system of bosons

Quantum chaos theory states that chaotic systems and their counterpart, integrable systems are characterized by qualitatively different distributions of distances between neighboring energy levels. Integrable systems have more symmetry structure making them easier to solve analytically, thus the distribution of energy levels follows Poisson statistics for such systems. For chaotic systems, the energy levels follow Wigner statistics. I have studied chaotic properties of a two dimensional quantum system of bosons in a harmonic trap, where my collaborators and I provide evidence for quantum chaos theory by showing that the distribution of energy eigenvalues for this chaotic system indeed follows Wigner distribution.

*Figure 1: Distribution of energy eigenvalues (black dots) of the chaotic theory studied follows Wigner statistics (green curve) and not Poisson statistics (red curve).*

## Theses defended in 2019

| | |
|---|---|
| Saskia Demulder I VUB | "Duality and resurgence in integrable sigma-models" 16 September 2019 (thesis advisors: Prof. Alexander Sevrin and Prof. Daniel C. Thompson). |
| Sibylle Driezen I VUB | "Geometrical approach to integrable and supersymmetric sigma models" 17 September 2019 (thesis advisors: Prof. Alexander Sevrin and Prof. Daniel C. Thompson). |
| Kévin Nguyen I VUB | "Gravity beyond General Relativity in anti-de Sitter and de Sitter spacetimes" – 18 September 2019 (thesis advisor: Prof. dr. Ben Craps). |
| Guillaume Valette I ULB | "New Limits for Large N Matrix and Tensor Models: Large D, Melons and Applications" 9 October 2019 (thesis advisors: Prof. Frank Ferrari and Prof. Stéphane Detournay). |
| Matthias Vereecken I VUB | "Aspects of astrophysical particle production and beyond the Standard Model phenomenology" 10 October 2019 (thesis advisors: Prof. dr. Alexander Sevrin, Prof. dr. Jorgen D'Hondt and Prof. dr. Nick Van Eijndhoven). |
| Vincent Luyten I VUB | "Non-linear dynamics in anti-de Sitter space and quantum chaos in spin chains" 15 October 2019 (thesis advisor: Prof. dr. Ben Craps). |

## Other awards

Dr. Charles Rabideau obtained a prestigious postdoctoral fellowship from the *Fonds Wetenschappelijk Onderzoek – Vlaanderen (FWO).*

Dr. Chris Blair obtained a prestigious senior postdoctoral fellowship from the *Fonds Wetenschappelijk Onderzoek – Vlaanderen (FWO)*.

## Other interesting events

Prof. Dr. Ben Craps was elected as the Dean of the Faculty of Sciences and Bio-Engineering Sciences at the VUB.

# TALKS AT CONFERENCES, SEMINARS AND SCHOOLS

## Aqeel Ahmed

*Neutral Naturalness at the LHC*
PLANCK 2019, University of Granada, Spain
4 June 2019

*A light scalar window at the LHC*
EoS be.h meeting, VUB, Brussels, Belgium
18 June 2019

*Dilaton portal to composite twin Higgs*
SCALARS 2019, University of Warsaw, Poland
13 September 2019

## Riccardo Argurio

*Goldstones, or not, in QFT and Holography*

- Nordita, Stockholm, Sweden
  19 May 2019
- University of Groningen, The Netherlands
  12 September 2019

*Phases of 3d gauge theories*

- Universita di Genova, Italy – 23 October 2019
- Universidad de Oviedo, Spain
  12 December 2019

## Alex S Arvanitakis

*The L-infinity algebra of the S-matrix*

- KU Leuven, Joint Belgian HEP seminars, Leuven, Belgium – 29 October 2019
- Humboldt University Berlin, Germany
  13 November 2019

## Glenn Barnich

*Charged black body radiation*

- Black Hole Initiative Colloquium, Harvard University, Cambridge, USA – 16 April 2019
- ITMP inaugural meeting: Recent Advances in Theoretical Physics of Fundamental Interactions, Moscow State University, Moscow, Russia
  10 June 2019

*Gravity with boundary conditions*

- 3 review lectures - Program: Gauge theories, supergravity and superstrings, Benasque Center of Science, Benasque, Spain – 17-20 June 2019
- Plenary talk – Quantum Theory and Symmetry XI, University of Montreal, Canada – 2 July 2019

*BMS current algebras*

Be.HEP Summer Solstice meeting 2019, Université de Liège, Belgium – 21 June 2019

*Gibbons-Hawking contribution from Casimir effect*

Supersymmetries and Quantum Symmetries-SQS'19, Yerevan Physics Institute, Yerevan, Armenia
26 August 2019

*Soft degrees of freedom, Gibbons-Hawking contribution & Casimir effect*

Humboldt Kolleg. Frontiers in Physics: From Electroweak to Planck Scales, Corfu Summer Institute, Corfu, Greece – 18 September 2019

*Symmetries and conservation laws in gauge field theories*

PhD lecture course - Universidad Autónoma de Madrid, Spain – 14-16 and 21-23 October 2019

*Soft degrees of freedom, Gibbons-Hawking contribution & entropy from Casimir effect*

- Workshop Beyond Lorentzian Geometry, University of Edinburgh, United Kingdom
  28 October 2019
- Ecole Normale Supérieure de Lyon, France
  4 November 2019
- Université de Genève, Switzerland
  11 November 2019

*Notes on BV-BFV quantization in the presence of boundaries*

Conference on Supergeometry, supersymmetry and quantization, Université du Luxembourg, Belval, Luxembourg – 16 December 2019

### Martin Bies

*Monoidal structures in Freyd categories*

Gap-Singular Meeting 2019, Lambrecht, Germany
19 August 2019

*Tensor products of finitely presented functors*

University of Oxford, United Kingdom
3 September 2019

*From F-theory Standard Models to Freyd Categories and back*

University of Pennsylvania, Philadelphia, USA
10 December 2019

### Chris Blair

*Non-Riemannian geometry of M-theory from Exceptional Field Theory*

- University of Cape Town, South Africa
  14 February 2019
- Theory Trinity College Dublin, Ireland
  27 March 2019

*Planes, branes and exceptional field theories*

- Imperial College London, UK – 29 May 2019
- University of Cambridge, UK – 30 May 2019

*Geometry and not (gong show talk)*

Theory At Sea, Oostende, Belgium – 7 June 2019

*Orbifolds and Orientifolds as O-folds (gong show talk)*

Strings 2019, Brussels, Belgium – 9 July 2019

*Doubled and non-relativistic string theory*

Nordita, Stockholm, Sweden – 18 November 2019

*Non-geometry and exotic branes (overview talk)*

AEI Potsdam, Germany – 3 December 2019

### Luca Ciambelli

*BMS & Asymptotic Symmetries in 4d Flat Space*

Avogadro meeting, Napoli, Italy
18-20 December 2019

### Geoffrey Compère

*Are quantum corrections on horizon scale physically relevant?*

COST conference, Athens, Greece
21 January 2019

*Analytic properties of High Spin and Large mass-ratio coalescences*

APC, Paris, France – 12 February 2019

*BMS and the information paradox*

CERN, Genève, Switzerland – 18 March 2019

*Some physics behind supertranslations and superrotations*

- Utrecht University, The Netherlands
  9 May 2019
- Imperial college, London, UK
  4 December 2019

*Signatures of High Spin in Gravitational Waveforms*

Harvard University, Cambridge, USA – 20 May 2019

*Lectures on gravitational waves*

Vienna University, Austria – 18-20 October 2019

### Ben Craps

*Elementaire Deeltjes. Het Brout-Englert-Higgsdeeltje: En Verder?*

UPV Brugge, Bruges, Belgium – 24 Januay 2019

*What is spacetime made of?*

Pint of Science Festival, Brussels, Belgium
22 May 2019

*Quantum chaos, thermalization and holography*

Theory at sea 2019, Ostend, Belgium – 6 June 2019

### Marine De Clerck

*Quantum chaos in the Ising spin chain*

Theory@Sea (gong show), Ostend, Belgium
7 June 2019

*Quantum chaos and Holography*

Université de Liège (Be.HEP Summer Solstice Meeting), Liège, Belgium – 21 June 2019

*Lyapunov growth in quantum spin chains*

University foundation (Francqui Symposium "Wavefunctions and entanglement in quantum field theory") Brussels, Belgium – 14 October 2019

Saskia Demulder

*Poisson-Lie T-duality and integrable deformations*

ETH, Zurich, Switzerland – 5 May 2019

Stéphane Detournay

*Anti Anti-de Sitter Black Holes*

- University Tsinghua Sanya, China
  19 January 2019
- ESI, Vienna, Austria – 18 March 2019

*Warped Flatland*

- Ecole Polytechnique Fédérale, Lausanne, Switserland – 27 May 2019
- Ecole Polytechnique CPhT, Palaiseau, France
  26 September 2019

*Warped Symmetries of the Kerr Black Hole*

Corfu Summer Institute, Corfu, Greece
14 September 2019

Sibylle Driezen

*Integrable deformed sigma-models with boundaries*

National and Kapodistrian University of Athens, Greece – 5 March 2019

*Integrable sigma-models with boundaries*

Strings, Cosmology and Gravity Student Conference, Munich, Germany – 2 April 2019

*Integrable lambda-deformations*

Integrable effective field theories and their holographic descriptions, Florence, Italy – 17 December 2019

*De weg van Unificatie, Eenheid en Harmonie in de Fysica*

Koninklijk Lyceum Antwerpen, Belgium
8 November 2019

Oleg Evnin

*Weakly nonlinear dynamics of strongly resonant systems*

Symmetry 2019 @ Suranaree U Tech, Korat, Thailand
15 January 2019

*Nonlinear perturbations in Anti-de Sitter spacetime*

- Kindai U, Osaka, Japan – 24 April 2019
- Yukawa Institute, Kyoto, Japan – 8 May 2019
- Nagoya University, Nagoya, Japan
  10 May 2019
- ICIMAF, Havana, Cuba – 19 August 2019

*Weakly nonlinear dynamics in AdS and BEC*

Turbulence of all kinds @ Osaka City U, Osaka, Japan – 25 April 2019

*Resonant systems, classical and quantum, integrable and chaotic*

Turbulence of all kinds @ Osaka City U, Osaka, Japan – 26 April 2019

*AdS and cold atoms*

- Keio University, Yokohama, Japan
  13 May 2019
- University of Tokyo at Komaba, Tokyo, Japan
  15 May 2019

*Weakly nonlinear dynamics in AdS*

Kazan Federal University, Kazan, Russia
21 May 2019

*Quantum resonant systems*

SYK Model and Related Topics @ Steklov Inst, Moscow, Russia – 6 June 2019

*Nonlinear dynamics in AdS and resonant Hamiltonian systems*

Time-like Boundaries in General Relativistic Evolution Problems @ BIRS-CMO, Oaxaca City, Mexico
1 August 2019

*Superintegrable quantum mechanics and resonant spacetimes*

SQS'19 @ University of Yerevan, Yerevan, Armenia
29 August 2019

*Resonant weakly nonlinear dynamics in AdS*

ETH Zurich, Switzerland – 22 October 2019

## Frank Ferrari

*Quantum Models for Black Holes: Sachdez-Ye-Kitaev and Generalizations*

Graduate course - Okinawa Institute of Science and Technology (OIST), Okinawa, Japan
March and April 2019

*New IR Behaviour in Melonic Quantum Mechanics*

International conference on Chaos, Holography and Coadjoint Orbits, University of Geneva, Switzerland
1 March 2019

*New IR Behaviour in Generalized SYK and Melonic Quantum Mechanics*

Workshop on Recent Developments In AdS/CFT, Okinawa Institute of Science and Technology (OIST), Okinawa, Japan – 3 April 2019

*On the large D expansion in Matrix Models*

Workshop on Large D methods and Holography, University of Utrecht, The Netherlands
28 May 2019

*CFT_1, SYK Models and Holographic Boundary Condition Changing Operators*

- Workshop "Quantum and Gravity in Okinawa", Okinawa Institute of Science and Technology (OIST), Okinawa, Japan – 25 July 2019
- Particle Physics Theory Seminar, Osaka University, Osaka, Japan – 30 July 2019

*On Large N and Large D in Matrix Models*

Particle Physics Theory Group, Osaka University, Osaka, Japan – 29 July 2019

## Marc Henneaux

*The BMS group at spatial infinity*

- 8th Bangkok Workshop on High Energy Theory, Chulalongkorn University, Bangkok, Thailand
7-11 January 2019
- University of Cape Town, South Africa
23 April 2019

*Asymptotic Symmetries of Gravity*

- Max Planck Institute for Physics, Munich, Germany – 22 January 2019
- University of Southern Denmark, SDU, Odense, Denmark – 25 February 2019

*Gravitation and Quantum Mechanics: the Biggest Crisis in Modern Physics?*

- Austrian Academy of Sciences, Vienna, Austria
15 March 2019
- Lomonosov State University, Moscow, Russia
8 October 2019

*Asymptotic symmetries of electromagnetism and gravity: a Hamiltonian study*

Erwin Schrödinger Institute, Vienna, Austria
22 March 2019

*Asymptotic symmetries of electromagnetism and Einstein gravity*

University of the Witwatersrand, Johannesburg, South Africa – 26 April 2019

*Asymptotic Symmetries of Electromagnetism and Gravity*

Institute for Theoretical and Mathematical Physics, Moscow, Russia – 9 October 2019.

*Asymptotic symmetries of electromagnetism and gravity - the asymptotically flat case*

Mini-workshop on black holes and symmetries, PUCV, Valparaiso, Chile – 15 November 2019

*Zero modes in AdS(3) gravity*

Adolfo Ibáñez University, Santiago, Chile
20 November 2019

*Asymptotic structure of electromagnetism and gravity in the asymptotically flat case*

Workshop: "Geometry and Duality", Max Planck Institute for Gravitational Physics, Albert Einstein Institute, Potsdam, Germany – 6 December 2019

*The antifield-BRST approach to (gauge) field theories: an overview*

Conference: "Exceptional Dimensions: A Conference in Honour of Bernard Julia", Institut Henri Poincaré, Paris, France – 17 December 2019

## Sam Junius

*A feeble window on leptophilic dark matter*

- Université Libre de Bruxelles (BPS 2019 Conference) – 22 May 2019
- UGent (EPS-HEP 2019 Conference)
12 July 2019

### Surbhi Khetrapal

*Quantum quench, thermalisation and chaos*

Chulalongkorn University, Bangkok, Thailand
10 January 2019

*Energy level splitting for weakly interacting bosons in a harmonic trap*

- Université Libre de Bruxelles, Belgium
  27 March 2019
- Tata Institute of Fundamental Research, Mumbai, India – 5 December 2019

### Viktor Lekeu

*Exotic fields and maximal supersymmetry in six dimensions*

ENS Lyon, France – 13 May 2019

*3d conformal geometry and 4d prepotentials for fermionic higher-spin fields*

Workshop on Supersymmetries and Quantum Symmetries – SQS'19, Yerevan, Armenia

27 August 2019

### Laura Lopez Honorez

*Interacting Dark matter versus warm dark matter*

IPPP, Durham, UK – 30 January 2019

*FIMP: from freeze-in to conversion doomed freeze-out*

Imperial college, London, UK – 14 March 2019

*(Some) Cosmological imprints of DM*

Mons University, Mons, Belgium – 19 April 2019

*Looking for dark matter in the 21 cm sky*

Workshop "News from the dark", Montpellier, France
21 May 2019

*Coannihilating Dark matter: from freeze-out to freeze-in*

- Invisibles 19 Workshop, Valencia, Spain
  10 June 2019
- Cosmo19 Conference Aachen, Germany
  3 September 2019

*Dark ages of dark matter*

Be.HEP Summer Solstice Meeting, Liège, Belgium
21 June 2019

*FIMPs: from freeze-in to conversion freeze-out*

- Conference Scalars 19, Warsaw, Poland
  12 September 2019
- DESY Theoryworkshop: QFT meets gravity, Hamburg, Germany – 26 September 2019

*Leptophilic Dark Matter from freeze-in to freeze-out*

BLV workshop, Madrid, Spain – 24 October 2019

### Alberto Mariotti

*Feebly coupled Dark Matter and long-lived particles at the LHC*

DESY, Hamburg, Germany – 6 May 2019

*Beyond the Standard Model and Supersymmetry*

Gottingen University (HASCO summer school), Gottingen, Germany – 23 July 2019

*Feebly-interacting dark matter and long-lived particles at the LHC*

University of Rome 3, Italy – 21 November 2019

### Javier Matulich

*Hypergravity*

- Universidad de Santiago de Chile, Santiago, Chile – 22 April 2019
- Centro de Estudios Científicos (CECs), Valdivia, Chile – 15 May 2019
- Universidad de Concepción, Chile
  22 May 2019
- Université de Mons, Belgium – 20 June 2019

*Three-dimensional conformal geometry and prepotentials for four-dimensional fermionic higher-spin field*

Université de Mons, Belgium – 21 November 2019

## Wout Merbis

*Three dimensional gravity and the orbit method*

- Fudan University, Shanghai, China
  12 March 2019
- Imperial College, London, UK
  1 May 2019

*Three dimensional supergravity and the coadjoint orbit*

University of Groningen, The Netherlands
16 April 2019

*Popular talk: "How do black holes store information?"*

- I love Science festival, Brussels, Belgium
  26 April 2019
- Pint of Science festival, Brussels, Belgium
  20 May 2019

## Saereh Najjari

*Collider Signals of the Mirror Twin Higgs through the Hypercharge Portal*

PLANCK2019, University of Granada, Spain
3-7 June 2019

*Collider Signals of Twin Higgs Model through the Higgs and Hypercharge Portals*

SCalars2019, University of Warsaw, Poland
11-14 September 2019

*A light Dilaton at the LHC*

IRN, Trascle@Bruxelles, ULB Bruxelles, Belgium
16-18 October 2019

## Kevin Nguyen

*A Graceful exit to the cosmological constant damping scenario*

- Vrije Universiteit Brussel, Belgium
  14 February 2019
- Sapienza University, Rome, Italy
  21 February 2019
- Institut des hautes études scientifiques, Cargèse, France – 9 May 2019
- Theory@sea, Ostend, Belgium – 6 June 2019

## Pierluigi Niro

*Isospin breaking effects and nucleon electric dipole moment in holographic QCD*

Università di Roma Tor Vergata, Rome, Italy
7 June 2019

*QCD domain walls and holography*

University of Swansea, UK – 6 December 2019

## Stefan Prohazka

*Spacetimes, symmetries and theories: beyond lorentzian geometry*

Universitat de Barcelona, Spain – 27 June 2019

*Maximally symmetric spacetimes reconsidered*

- Edinburgh Mathematical Society, Edinburgh, Scotland – 28 October 2019
- TU Wien, Vienna, Austria – 5 November 2019

## Charles Rabideau

*Emergent classical spacetime from microstates of an incipient black hole*

IPhT Saclay, Saclay, France – 6 March 2019

*Spacetime from entanglement*

Brout Englert Lemaître Center, Brussels, Belgium
30 April 2019

*The dual of non-extremal area: differential entropy in higher dimensions*

Yukawa Institute for Theoretical Physics, Kyoto, Japan – 24 June 2019

*Entanglement in gauge theory and the soft modes of an incipient black hole*

Francqui Symposium, Brussels, Belgium
17 October 2019

## Max Riegler

*(Q)NEC and Flat Space Holography in 3D*

YITP, Kyoto University, Japan – 19 April 2019

*Shockwaves, the Unruh Effect and Black Hole Information Loss (Poster)*

YITP, Kyoto University, Japan – 12 June 2019

### Ali Seraj

*Gravitational flux balance equations from BMS symmetries*

ULB, Brussels, Belgium – 7 November 2019

*BMS flux-balance equations as constraints on the gravitational radiation*

XII Black Holes Workshop, Guimarães, Portugal
20 December 2019

### Alexander Sevrin

Numerous presentations concerning *the Einstein Telescope and the R&D facility ETpathfinder* for decision makers and politicians, industrialists, scientists and lay people.

### Daniel Thompson

*Integrable deformations and Generalised Dualities*

- Mainz Institute for Theoretical Physics, Mainz, Germany – 8 May 2019
- University of Hertfordshire SEMPS, Hertford, UK
  29 May 2019
- University of Santiago De Compostela, Spain
  5 June 2019

### Hongbao Zhang

*Dark soliton and Wave Turbulence in Holographic Superfluids*

Wurzburg University, Wurzburg, Germany
5 February 2019

*Landau Instability and Transient Turbulence of Laminar Superflow*

Peking University, Beijing, China – 27 December 2019

# PUBLICATIONS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[2] A. Ahmed, A. Carmona, J. Castellano Ruiz, Y. Chung and M. Neubert, "Dynamical origin of fermion bulk masses in a warped extra dimension," JHEP 1908 (2019) 045 doi:10.1007/JHEP08(2019)045 [arXiv:1905.09833 [hep-ph]].

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[4] R. Argurio, M. Bertolini, F. Mignosa and P. Niro, "Charting the phase diagram of $QCD_3$," JHEP 1908 (2019) 153 [arXiv:1905.01460 [hep-th]].

[5] R. Argurio, D. Naegels and A. Pasternak, "Are there Goldstone bosons in $d \leq z + 1$ ?," Phys. Rev. D 100 (2019) no.6, 066002 [arXiv:1903.11417 [hep- th]].

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[7] V. Balasubramanian, B. Craps, M. De Clerck and K. Nguyen, "Superluminal chaos after a quantum quench," JHEP 1912 (2019) 132 doi:10.1007/JHEP12(2019)132 [arXiv:1908.08955 [hep-th]].

[8] V. Balasubramanian, B. Craps, T. De Jonckheere and G. Sárosi, "Entanglement versus entwinement in symmetric product orbifolds," JHEP 1901 (2019) 190 doi:10.1007/JHEP01(2019)190 [arXiv:1806.02871 [hep-th]].

[9] V. Balasubramanian, D. Berenstein, A. Lewkowycz, A. Miller, O. Parrikar and C. Rabideau, "Emergent classical spacetime from microstates of an incipient black hole," JHEP 1901 (2019) 197 doi:10.1007/JHEP01(2019)197 [arXiv:1810.13440 [hep-th]].

[10] V. Balasubramanian, N. Jokela, A. Pnni and A. V. Ramallo, "Information flows in strongly coupled ABJM theory," JHEP 1901 (2019) 232 doi:10.1007/JHEP01(2019)232 [arXiv:1811.09500 [hep-th]].

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[13] L. Barack et al., "Black holes, gravitational waves and fundamental physics: a roadmap," Class. Quant. Grav. 36 (2019) no.14, 143001 [arXiv:1806.05195 [gr-qc]] (G. Compère).

[14] G. Barnich, "Black hole entropy from nonproper gauge degrees of freedom: The charged vacuum capacitor," Phys. Rev. D 99 (2019) no.2, 026007 [arXiv:1806.00549 [hep-th]].

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[18] E. A. Bergshoeff, W. Merbis and P. K. Townsend, "On-shell versus Off-shell Equivalence in 3D Gravity," Class. Quant. Grav. 36 (2019) no.9, 095013 [arXiv:1812.09205 [hep-th]].

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## PREPRINTS

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# RESEARCH HIGHLIGHTS OF OTHER SCIENTISTS

## CONNECTED WITH THE INSTITUTES

**ALGC Research Group I VUB**

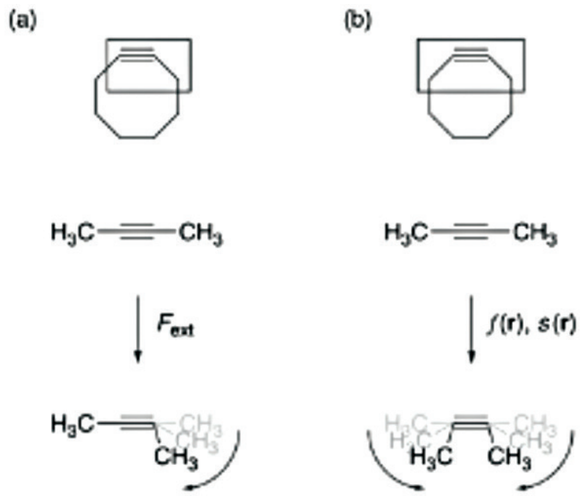
Group of Professors Frank De Proft, Frederik Tielens, Mercedes Alonso, Freija De Vleeschouwer and Professor Emeritus Paul Geerlings

In recent years the ALGC Research Group has been extending its long-standing research interest in Conceptual Density Functional Theory [1] in a natural way along new research lines on the basis of the experience gained in various aspects of Density Functional Theory. Research Lines have been launched on Molecular Electronics, on Molecular Switches, on Inverse Design and on the study of molecular behaviour in the molecules' real environment upon reactions, i.e. in most cases a solution, requiring ab initio Molecular Dynamics and Metadynamics Simulations. Beyond and along these lines various applied quantum chemical studies are performed applying DFT based concepts on a variety of substrates most often carried out in direct interaction with experimentalists. Recently, as of the appointment of Prof. Frederik Tielens, a new applied research line has been opened into the field of Materials Modeling, characterizing, at the atomic level, inorganic, organic and biological solid materials, especially at the interphases.

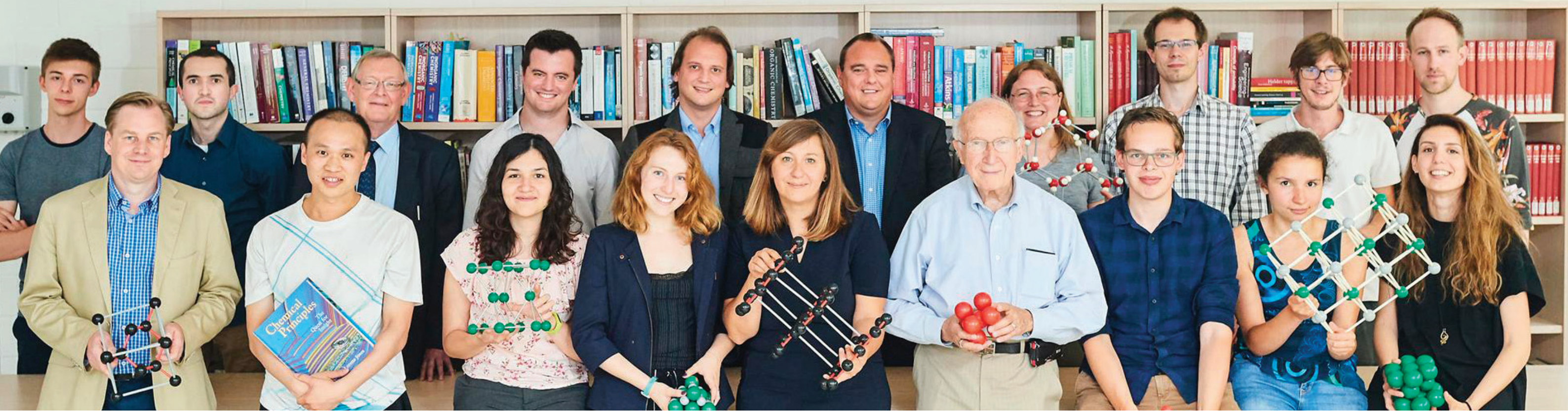
In this 2019 Report attention is paid to fundamental work in Conceptual DFT and Chemical Reactivity, Inverse Design, Molecular Switches, Applied Quantum Chemistry and Materials Modelling illustrating the broadening of the scope of the research activities of the ALGC group with combined attention to both fundamental and applied aspects of Quantum Chemistry.

### Conceptual DFT and Chemical Reactivity

Concerning the Conceptual DFT part particular attention was paid with Dr. Tom Bettens to extending the scope of Conceptual DFT to the vibrant field of Molecular Mechanochemistry [2] by introducing mechanical forces in the energy functional, thus creating a formal and computational framework to test the sensitivity of molecules to external mechanical forces. After an introductory study on diatomics [3] involving forces of stretching, the theory has now been extended to introduce bending forces to shed light on (the hunt for) reactive alkynes in bio-orthogonal click reactions [4] [5].

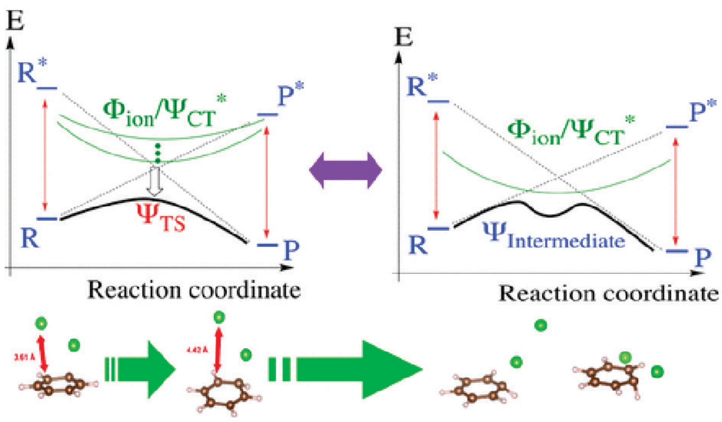



As a second example in this line of research the collaboration with Dr. Robert Balawender (Polish Academy of Sciences) should be mentioned, deepening and exploiting the concept of alchemical derivatives, i.e. derivatives of the energy of a molecule when one nucleus is replaced by another. This ansatz was previously shown to be a step forward in the exploration of the huge Chemical Compound Space. In recent work alchemical transformations between atoms have been explored changing both the nuclear charge and the number of electrons. In this way the energy of an atom (say N) could be evaluated starting from the energetic properties only of its neighbor (C or O) within chemical precision (less than 1 kcalmol$^{-1}$). A similar ansatz was also used to evaluate, hard -to- obtain- first and second negative atomic electron-affinities. [6]

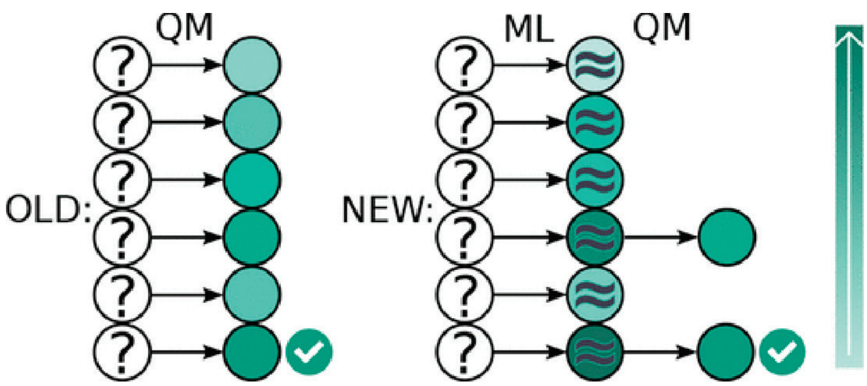


A somewhat unusual review paper has been published on the present status of Conceptual DFT with a selection of prospects and issues to be addressed in the near future prepared for and refined after a round table discussion between leading scientists in this field at a conference in Changsha in December 2018. [7]

Reactivity as such was discussed in two collaborations each one involving Post Doctoral associate Thijs Stuyver. With Nobel Laureate Roald Hoffmann (Cornell University), and as a natural sequel to previous work on the importance of (di)radical character in molecular conductance [8], an extensive review was published in Chemical Reviews on the understanding of the reactivity of biradicals and how that may differ from monoradicals [9]. Together with Sason Shaik (The Hebrew University of Jerusalem), the classical electrophilic aromatic substitution reaction has been re- scrutinized combining DFT and Valence Bond calculations resulting in a unifying framework that elucidates many surprising mechanistic features uncovered in recent years. A particular aspect was that the external oriented electric field effects were explicitly incorporated and led to the formulation of guiding principles for the design of improved heterogeneous catalysts. [10]




## Inverse Design




In the ongoing investigations on Inverse Design [11] in which Chemical Space is explored with the aim to design molecules with specific, optimized properties, Prof. De Vleeschouwer showed how this procedure can be accelerated by exploiting predictive techniques (machine learning) on quantum chemical properties via databases constructed on-the-fly. [12]

Applications in the field of redox-chemistry, in particular the design of efficient redox flow batteries, are under its way.

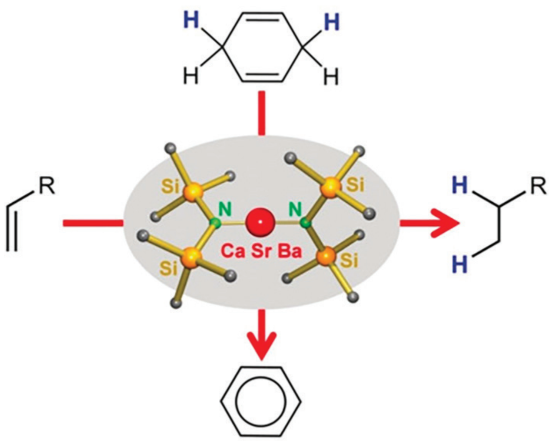
## Molecular Switches

Molecular Switches based on expanded porphyrins have now been explored in ALGC for some years under the impetus of Prof. Mercedes Alonso [13], with particular attention to topological switches from Hückel to Möbius rings under the influence of external stimuli. This year, in collaboration with Prof Jan Martin from the Weizmann Institute of Science, an in depth study has been undertaken about the performance of a broad variety of electronic structure methods for an accurate description of Hückel Mobius interconversions in extended $\pi$ systems concentrating both on the thermochemistry and the kinetics of topology interconversions. The benchmark, against the most refined and performing wave function methods exploitable for systems of this size, of a variety of DFT approximations will be of great value in further explorations of this research line [14]. From the more conceptual side and in line with a long standing interest of the group in information theoretical approaches [15] an interesting link has been established between the energy profiles of some selected hexaphyrins upon the dynamical interconversion between Möbius and and Hückel aromaticity using both energy decomposition and information theoretic approaches providing new insights into conformational stability, aromaticity and anti-aromaticity for these species. [16]

## Applied Quantum chemistry

Two prototype examples of applied quantum chemistry are presented, both in direct interaction with experimental chemists.

In 2018 a collaboration with Prof. Harder from the Inorganic Chemistry Department of the University of Erlangen-Nürnberg was set up on the catalytic activity of early (group 2) main group metals (Mg, Ca, Sr, Ba) [17] in search for replacing transition metal elements by early main group metals as catalysts driven by both economic and environmental profit. As a sequel to a previous study on alkene direct and alkene transfer hydrogenation [18], DFT calculations were exploited to study the alkene transfer hydrogenation (TH) of a variety of alkenens with simple earth alkaline $AeN''_2$ catalysts (Ae=Ca,Sr,Ba; N"= N $(SiMe_3)_2$) using 1,4-cyclohexadiene as H source.

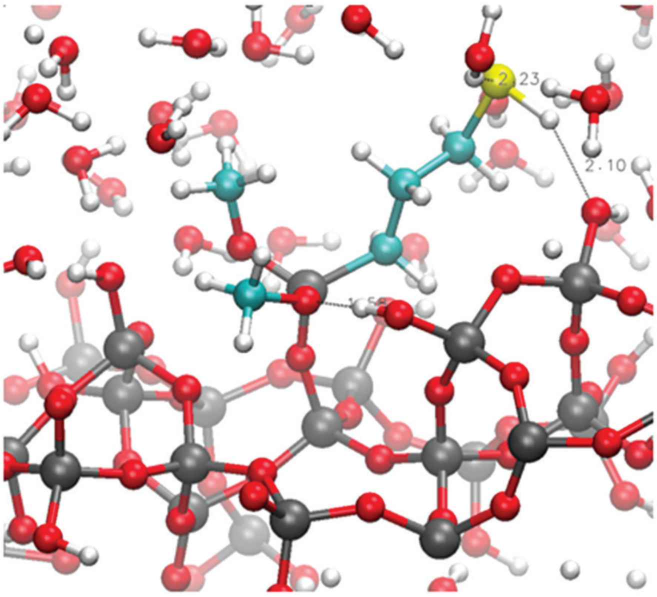

This study supported the formation of a meta hydride species by deprotonation of 1,4 cyclohexadiene followed by a H transfer.

In a collaboration with the Laboratory for Molecular Design and Synthesis of the KULeuven (Wim De Borggraeve) Drs. Ruben Van Lommel and Mercedes Alonso used a multiscale bottom-up computational approach (involving both DFT and Molecular Dynamics) to virtually zoom in on non-covalent interactions (NCI), a long standing theme in ALGC [20] that are key for the supramolecular hydrogelation of bis- urea based gelators. In this way the efficiency of hydrogelation measured by means of rheological experiments could be rationalized. [21]

## Materials Modelling

In this research line two examples of the subfields and systems that were addressed are the reactivity of mercaptosilanes with silica used in the preparation of hybrid materials and the unraveling of the amorphous nanostructure of non- ferrous metallurgy slags by molecular dynamics calculations.

In a collaboration with the Department of Materials Engineering of the KULeuven a comprehensive description was given of the nano-structure of CaO-FeO-$SiO_2$ slag by using molecular dynamics simulations in conjunction with experimental data from X-ray and neutron pair distribution function studies [22]. The other example in an ongoing collaboration with experimental groups at the universities of Poznan and Cracow, involves the combined use of periodic DFT and ab initio molecular dynamics simulations to scrutinize the structure of anchored mercaptosilanes on the surface of mesoporous amorphous silica. Both experimental data (IR, Temperature Programmed Desorption, Catalytic Activity Tests) and the theoretical results highlight the importance of residual water in the functionalized pores activating the catalytic site in these pores. [23]

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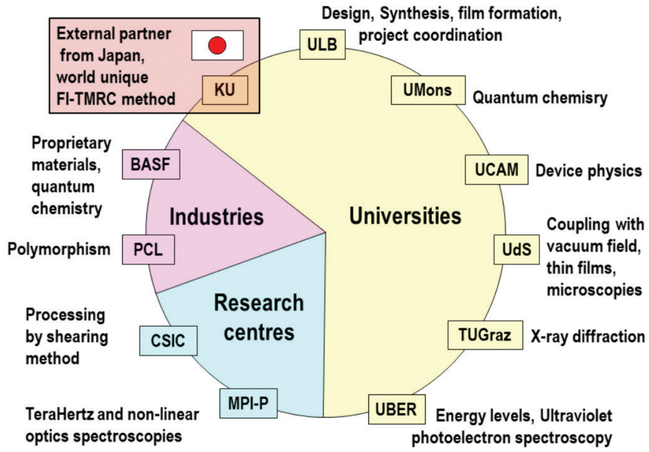
## Group of Professor Yves Geerts

The Marie Sklodowska Curie program[1] of the European Commission will support the UHMob project coordinated by Yves Geerts, over four years[2]. The scientific objective of UHMob is to gain a fundamental understanding of charge transport mechanisms in molecular semiconductors. To this goal, best-performing and well-characterized materials will be studied by a complementary set of methods, including field effect transistors but also optical methods such as terahertz spectroscopy and field-induced time-resolved microwave conductivity (FI-TRMC). UHMob will also explore the coupling of molecular semiconductors with the vacuum electromagnetic field, that is a radically new physical concept holding great promises to modulate optoelectronic properties of materials.

The mission of UHMob is to widen the career perspectives of 15 Early-Stage Researchers (ESRs) by allowing them to obtain a PhD in a truly multidisciplinary and cross-sectional research environment. The intensive training program, that largely takes advantage of student exchange, is supported by recent scientific breakthroughs of UHMob partners to offer to ESRs the opportunity to carry research at the forefront of Science.




**Overview of Complementarities between partners of UHMob consortium**

The construction of UHMob consortium, has been catalyzed by some activities of the Solvay Institutes, in particular the Colloquia of Thomas Ebbesen from the University of Strasbourg, Feb. 2014 and of Mischa Bonn, Max Planck Institute, Dec. 2014, but also the workshop entitled: "Charge, spin, and heat transport in organic semiconductors", Nov. 2016. The work plan of UHMob is also backed up by long-lasting collaborations of Guillaume Schweicher[3] and Yves Geerts with Jérôme Cornil, David Beljonne, and Roberto Lazzaroni at the University of Mons, and with Henning Sirringhaus at the University of Cambridge.

Recently, they have shown together that some intermolecular vibration modes are particularly detrimental to the transport of electrical charges in organic semiconductors.

Yves Geerts and Guillaume Schweicher have recently published a large review paper that critically discusses the current fundamental understanding of organic semi-conductors[4] and the future perspectives of the field[5].

[1] *https://ec.europa.eu/programmes/horizon2020/en/h2020-section/marie-sklodowska-curie-actions*

[2] *April 1, 2019 – March 31, 2023, budget of € 3 927 322 to support the doctoral education of 15 PhD students. https://www.uhmob.eu/*

[3] *Guillaume Schweicher is currently a FNRS Postdoctoral Researcher in the group of Yves Geerts*

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# THE ROBERT BROUT PRIZES AND THE 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 (one prize at the ULB, one prize at the VUB).
- the Robert Brout Prizes, to be awarded to the best students finishing their master studies in physics, provided they have a brilliant curriculum (one prize at the ULB, one prize at the VUB).

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

In 2019, the prizes have been awarded to:

- Bram Huygens (Ilya Prigogine Prize VUB)
- Maxime Bonsir (Ilya Prigogine Prize ULB)

- Caroline Jonas and Adrien Druart (Robert Brout Prize ULB)

# APPENDIX

## The Solvay Science Project

Alexiou Yoanna, Université libre de Bruxelles, yalexiou@ulb.ac.be

### Introduction

À l'époque du web 2.0, la question de la valorisation d'un patrimoine matériel ne se pose déjà presque plus pour la majorité des bibliothèques et des centres d'archives en Belgique et en France. La réflexion autour de la valorisation du patrimoine culturel, qu'il soit scientifique, historique, social, politique ou économique, à l'aide des « nouvelles technologies » et de l'usage du web s'est largement développée depuis la fin des années 1990[1]. Mais en ce qui concerne la valorisation du patrimoine culturel liée aux sciences naturelles et exactes, peu de travaux existent à ce jour en Belgique. Financé par la politique scientifique fédérale, le projet d'encyclopédie « BESTOR », mis en ligne en 2008 est un exemple de wiki dédié à l'histoire des sciences. Il existe également des projets de valorisation du patrimoine culturel scientifique financés par le secteur privé. Les entreprises Solvay, par exemple, ont mis en ligne en 2017 une exposition Google Arts & Culture destinée à raconter l'histoire d'Ernest Solvay et son rôle en tant que mécène. À la même période, le projet de diffuser une base de données et une exposition virtuelle germe au sein du Comité des Archives des Instituts internationaux de physique et de chimie Solvay (IIPCS). Le 07 mai 2018, le Solvay Science Project, fruit du travail d'une équipe interdisciplinaire, voit le jour [2].

### Un riche patrimoine matériel et immatériel

Les IIPCS localisés à Bruxelles sont riches d'une histoire sociale et scientifique belge et internationale s'étendant du début du XX$^{e}$ siècle à nos jours. Fondés sous la forme de deux institutions autonomes : l'Institut international de physique Solvay en 1912 et l'Institut international de chimie Solvay en 1913, ils sont connus pour l'organisation des Conseils de Physique et Conseils de Chimie. Plus précisément, c'est le Conseil de Physique organisé en 1911 qui sera le point de départ de cette aventure scientifique. Sous la houlette, d'Hendrik Lorentz et Ernest Solvay, 24 éminents savants, spécialistes de la chimie et de la physique fondamentale, se réunissent à Bruxelles durant quatre jours en novembre 1911. L'historiographie et les scientifiques soutiennent l'importance de cet événement considéré comme fondateur de ce que l'on appelle aujourd'hui, la physique moderne ou encore la physique des quantas, de l'infiniment petit [3].


*Premier Conseil de Physique Solvay, photographie de groupe, 1911. (Archives de l'Université libre de Bruxelles. Disponible également en ligne : http://www.thesolvayscienceproject.be/exhibits/show/the-solvay-science-project/th–me-1 )*

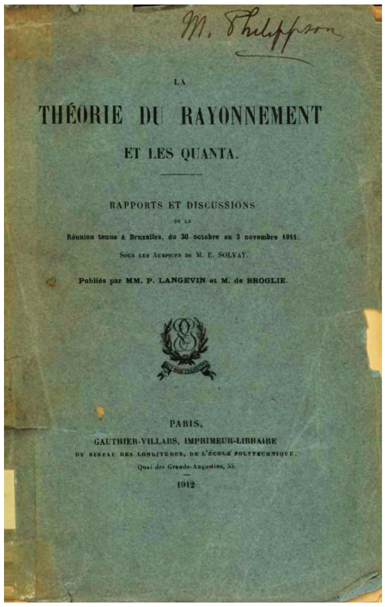
Depuis 1911, l'on recense 27 Conseils de Physique et 25 Conseils de chimie. De nombreuses bourses pour les chercheurs internationaux et subsides pour les chercheurs belges ont également été distribués entre 1911 et 1950 permettant, entre autres, la confection du microscope électronique de Robert Marton ou celle du polarimètre de Robert Descamps. Une large production scientifique existe. Elle se compose de la publication des comptes-rendus – communément appelées « Proceedings » – des Conseils Solvay et d'un nombre impressionnant d'archives conservées à Bruxelles et à l'étranger. En effet, le caractère international des IIPCS et de son comité scientifique induit une dispersion des archives un peu partout en Europe, aux États-Unis et en Russie. Malgré tout, une grande partie des archives administratives sont conservées à l'Université libre de Bruxelles (ULB) en raison du lien historique qui unit les deux institutions. À leur création, les IIPCS étaient la « propriété » d'Ernest Solvay. Ils ont été fondés dans l'optique de s'inscrire dans son projet de « cité internationale des sciences » située au Parc Léopold, une cité des sciences qui devait regrouper les Instituts de Sociologie, de Physiologie, d'Anatomie, d'Hygiène et ceux de physique et chimie [4]. Ils sont créés pour une durée de 30 ans et soutenus financièrement par la famille Solvay. Après le décès d'Ernest Solvay, ils sont légués à l'ULB qui assurera la continuité de la gestion administrative et financière. Celle-ci pourvoira des locaux pour l'organisation des Conseils à Bruxelles jusqu'en 1963 lorsque les instituts fusionnent en un seul organisme avant de devenir une ASBL en 1972. L'ensemble de leur production scientifique se révèle être un patrimoine matériel et immatériel important pour l'histoire des sciences et les recherches en physique et chimie fondamentales. Durant de longues années, les archives ont été inexploitées. Seuls les documents de l'Institut de Physique de 1910 à 1958 avaient été classés. En 2016 et 2019, les archives de l'Institut de Physique de 1958 à 2003 et celles de l'Institut de chimie de 1913 à 2003 sont enfin ouvertes à la recherche. Ce patrimoine retrouvé est le point de départ d'un vaste projet de valorisation encore en construction : le Solvay Science Project.

## Des objectifs opposés à concilier

De nombreux outils, payants ou open source, sont mis à disposition des bibliothèques et des musées pour assurer la valorisation de leur patrimoine numérique et numérisé. Pour les IIPCS, cette question de valorisation ne pouvait se faire sans une collaboration étroite avec les bibliothèques de l'ULB et de la VUB qui ont déjà mis en place divers dispositifs de valorisation de documents accessibles en ligne. Ce type de valorisation au travers d'une base de données appelée Digithèque vise majoritairement un public d'experts ou, du moins, un minimum informé tel que l'étudiant ou le chercheur. Dans ce sens, la première partie du projet, à savoir la numérisation des « proceedings » des Conseils et la mise en ligne de 24 d'entre eux au sein d'une base de données répondait au principe itératif de la science qui anime les Conseils Solvay puisqu'il leur permettait de diffuser les savoirs scientifiques produits au sein des Conseils de 1911 à nos jours partout dans le monde scientifique et académique.

Ainsi, le physicien d'aujourd'hui peut relire le physicien de 1911, quel que soit le lieu où il se trouve.

Il peut, par exemple, reprendre la recherche liée aux théories de la chaleur proposées par Max Planck et Albert Einstein là où elle s'était arrêtée en 1911. En adoptant une nouvelle lecture de ces théorèmes à l'aide des connaissances actuelles, le physicien de 2019 permet à la science d'avancer un pas plus loin. Ce besoin de diffuser les savoirs en ligne pour un institut international qui accueille des éminences scientifiques venues du monde entier depuis les années 1910 a été facilement rempli par les techniques informatiques et les outils déjà existants. Cependant, les IIPCS souhaitent aller au-delà de cette transmission des savoirs au sein du




*Page de garde du Proceedings du Premier Conseil de Physique Solvay, « La théorie du rayonnement et les quanta : rapports et discussions de la réunion tenue à Bruxelles du 30 octobre au 3 novembre 1911 » sous les auspices de M. E. Solvay, publié par MM. P. Langevin et M. de Broglie, 1912. (Archives de l'Université libre de Bruxelles, disponible également en ligne: http://www.thesolvayscienceproject.be/items/show/1069#?c=0&m=0&s=0&cv=0 )* cénacle des chercheurs. Après plus de 100 ans d'existence, ils souhaitent se rapprocher du grand public, notamment de la jeunesse, pour inspirer les élèves en secondaire et les intéresser aux sciences physiques et chimiques. Il s'agissait dès lors, non plus de valoriser les archives et le patrimoine dans un souci de diffusion au sein de la communauté scientifique, mais de vulgariser ce patrimoine, de le replacer dans son contexte historique, social et politique et de le présenter sous une forme la plus pédagogique possible, à savoir, dans notre cas, « l'exposition virtuelle ».

## Conception du projet

En 2016, le logiciel qui semblait être le plus approprié à la demande des Instituts était le logiciel « OMEKA ». Cette plateforme open source créée par le Center for History and New Media (CHNM) de l'Université George Mason (Virginie, USA) a été utilisé par de nombreuses bibliothèques et universités. L'intérêt d'« OMEKA » pour les besoins du Solvay Science Project était double. D'une part, il permettait de diffuser une base de données des archives et proceedings déjà numérisés destinés à un public expert. D'autre part, il permettait de créer une « exposition virtuelle » racontant l'histoire des Conseils et des Instituts Solvay en deux niveaux de lecture : un public « amateur » et un public ayant déjà acquis la connaissance nécessaire pour comprendre certains concepts scientifiques qui y sont développés. Il était donc possible d'allier diffusion des savoirs pour le monde scientifique et vulgarisation de ceux-ci pour le grand public, au sein d'un même site web. Il a, dès lors, été question de choisir au sein des proceedings et des 550 documents sélectionnés pour apparaitre dans la section « base de données », une centaine de documents, de photographies, d'illustrations à mettre en avant dans la section « exposition ». Cette dernière suit un fil narratif linéaire, mais est aussi consultable sous forme de « mapping » — une navigation en « réseau », non linéaire, que les « tags » et hyperliens permettent. Pour offrir une navigation plus intuitive au gré des intérêts de l'utilisateur, une photographie des membres du premier Conseil de physique Solvay a été rendue interactive. En cliquant sur le visage de l'un ou l'autre participant, le lecteur peut naviguer vers leurs biographies, vers une thématique précise de l'exposition ou vers la liste des documents d'archives numérisés qu'ils ont produits dans le cadre de leur fonction au sein des Instituts. Dans la gamme des techniques permettant la vulgarisation des savoirs, une série d'interviews et de conférences avec des membres de la Commission administrative et du Comité scientifique des Instituts, encore actifs de nos jours, ont été mis en ligne. Un autre moyen de vulgariser cette histoire a pris forme dans l'élaboration d'une capsule vidéo interactive de 7 min, réalisée par Kenneth Bertrams et Daniel Cattier, afin de servir d'introduction à l'exposition virtuelle. Cette capsule revient sur l'histoire des premiers Conseils de physique Solvay et la rupture que provoquera la Première Guerre mondiale dans les relations scientifiques internationales modifiant la manière dont se développeront la chimie et la physique après la Grande Guerre. Soutenu et produit par l'ULB et la VUB, le site est disponible en français, en anglais et en néerlandais. En raison du caractère international de l'Institut, la version anglaise est celle qui est la plus visitée depuis la mise en ligne de l'exposition.

## Un pari réussi ?

Vulgariser l'histoire d'un institut qui produit des savoirs scientifiques complexes n'est pas chose facile. Le Solvay Science Project représente donc un projet d'envergure pour les IIPCS et les équipes de l'ULB et de la VUB. Néanmoins, le site web, outil qui se veut pérenne, demande une mise à jour régulière des contenus, pour continuer à intéresser le grand public. Dans ce sens, les futures collaborations de l'IIPCS avec d'autres institutions européennes permettront d'alimenter la base de données du projet, mais aussi d'écrire l'histoire encore inconnue des Conseils de Chimie. L'objectif n'est plus, cette fois, de transmettre les savoirs, dans un souci de soutenir et respecter le principe itératif de la science, mais plutôt de les vulgariser pour intéresser les jeunes générations et leur montrer que les sciences fondamentales sont aussi tout autre chose une fois enseignées en dehors des bancs de l'école. Dès lors, un nouveau défi s'offre à cet outil, celui de contribuer à l'envergure internationale des IIPCS en réunissant toutes les archives conservées en dehors de Bruxelles, au sein de ce même site web. Cette nouvelle étape n'est réalisable qu'avec le soutien de collaborateurs internationaux comme l'École Supérieure de Physique et de Chimie industrielle de Paris et Paris Sciences et Lettres, par exemple. Ces derniers disposent déjà d'un vaste « corpus Solvay » numérisé et accessible sur leur bibliothèque numérique PSL-Explore. Ce projet a également posé plusieurs questions relatives aux droits d'auteurs, à la diffusion des contenus en libre accès et à leur usage ou réutilisation par les enseignants dans le cadre de leur cours par exemple. Ces questions complexes ont occupé — et occupent encore actuellement — une grande place lors de l'élaboration de ce projet.

## Pour conclure

Le Solvay Science Project est une initiative des IIPCS, de l'ULB et la VUB visant à valoriser leur patrimoine matériel et immatériel à l'aide des outils du web 2.0. Sans préjuger des nécessaires mises à jour et améliorations qui lui permettront de garder son caractère pérenne, le projet a rempli la mission qu'il s'était imposée à sa conception, celui d'assurer la diffusion des savoirs scientifiques dans un souci de vulgarisation et de contextualisation historique. Il est désormais possible au plus grand nombre de saisir l'histoire de ces Instituts, créés au siècle dernier, et qui continuent de jouer un rôle essentiel au sein de notre « société de la connaissance ».

Alexiou Yoanna

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■ Il s'agit d'une première dans l'histoire de l'astronomie et d'un défi technique.

■ Un collectif de scientifiques a réalisé une image d'un trou noir, situé à 50 millions d'années-lumière de la Terre.

■ "C'est comme observer un grain de moutarde à Washington depuis Bruxelles."

# Voici la toute première image d'un trou noir

À quoi ressemble un trou noir? Nous avons désormais la réponse. Des astronomes du monde entier, réunis dans le projet Event Horizon Telescope (EHT), ont dévoilé mercredi le résultat d'une observation croisée visant à capturer l'image d'un trou noir, une première dans l'histoire de l'astronomie. *"C'est une immense avancée pour l'humanité"*, a déclaré Carlos Moedas, commissaire européen chargé de la Recherche, qui présidait à Bruxelles l'une des six conférences de presse tenues à travers le monde, simultanément. *"Voici le noyau de la galaxie M87. C'est la première image d'un trou noir. Vous avez sans doute vu jusqu'ici beaucoup d'images de trous noirs, mais c'était des simulations, des animations. Mais ce qui rend précieuse celle-ci, c'est qu'elle est enfin vraie"*, a indiqué Heino Falke, l'un des scientifiques du EHT, dévoilant l'image de ce qu'il décrit comme ressemblant à un *"anneau de feu"*. Si elle est floue, ce n'est pas étonnant: *"À cette énorme distance, c'est comme observer un grain de moutarde à Washington depuis Bruxelles."*

### Étoiles aplaties, étirées, disloquées

L'image montre la "silhouette" du trou noir: un disque noir, avec autour de celui-ci un halo de lumière asymétrique. Massifs, gloutons, surpuissants: les trous noirs sont des objets qui n'émettent pas de lumière, mais ils agissent comme des "lentilles gravitationnelles", c'est-à-dire qu'ils vont dévier les rayons lumineux quand ils passent près de leur "corps" – "l'horizon" du trou noir. En gros, un trou noir "absorbe" la matière qui arrive à ce point de non-retour qu'est son horizon; mais si elle passe à côté, elle est déviée.

Concrètement, sous l'effet de l'énorme attraction gravitationnelle d'un trou noir, les étoiles trop proches sont aplaties, étirées, puis disloquées, le gaz porté à des chaleurs extrêmes. Gaz et morceaux d'étoiles tournent en spirale autour du trou noir pour finalement y plonger, en générant un sursaut brillant de lumière ultraviolette. *"La lumière du halo sur l'image vient de gaz et de matière proches du trou noir, qui s'échauffent en étant accélérés par la gravitation du trou noir"*, détaille le physicien belge Geoffrey Compère. *La lumière la plus intense a un spectre radio à haute fréquence, c'est cette lumière qui est observée par les télescopes. À cause du trou noir, cette lumière a une forme caractéristique: la silhouette du trou noir, noire au milieu et avec un halo de lumière autour, avec une asymétrie due à la rotation du trou noir et celle de son disque d'accrétion (matière autour de son orbite). Cette rotation induit un effet d'entraînement des rayons lumineux dans le sens de la rotation, ce qui crée cette asymétrie."*

Les trous noirs ont été théorisés, modélisés, détectés, mais jamais observés directement dans le spectre de la lumière (lire ci-contre). Selon la loi de la relativité générale publiée en 1915 par Albert Einstein, qui théorise leur fonctionnement, l'attraction gravitationnelle exercée par ces "monstres" est telle que rien ne peut s'en échapper, ni la matière ni la lumière, quelle que soit la longueur d'onde. Résultat: ils sont invisibles.

> *"Une photo, c'est la preuve définitive de l'existence des trous noirs."*
> **Jean-Pierre Luminet**
> Astrophysicien français

Pour contourner ce handicap de taille, les astronomes cherchent à observer le monstre par contraste, sur la matière qui l'entoure. En outre, un trou noir est un objet céleste qui possède une masse extrêmement importante dans un volume très petit. C'est un peu comme si la Terre était comprimée dans un dé à coudre. Pour voir des objets si petits, il faut un télescope de grandes dimensions.

En avril 2017, huit télescopes répartis à travers le monde avaient ciblé simultanément deux trous noirs avec un objectif: tenter d'en obtenir une image. Depuis deux ans, la communauté scientifique attendait le résultat. *"Une photo, c'est la preuve définitive de l'existence des trous noirs"*, s'enthousiasme Jean-Pierre Luminet, astrophysicien au CNRS français, auteur de la première simulation numérique d'un trou noir en 1979. *"Même dans la communauté scientifique, il y a encore pas mal de résistance."*

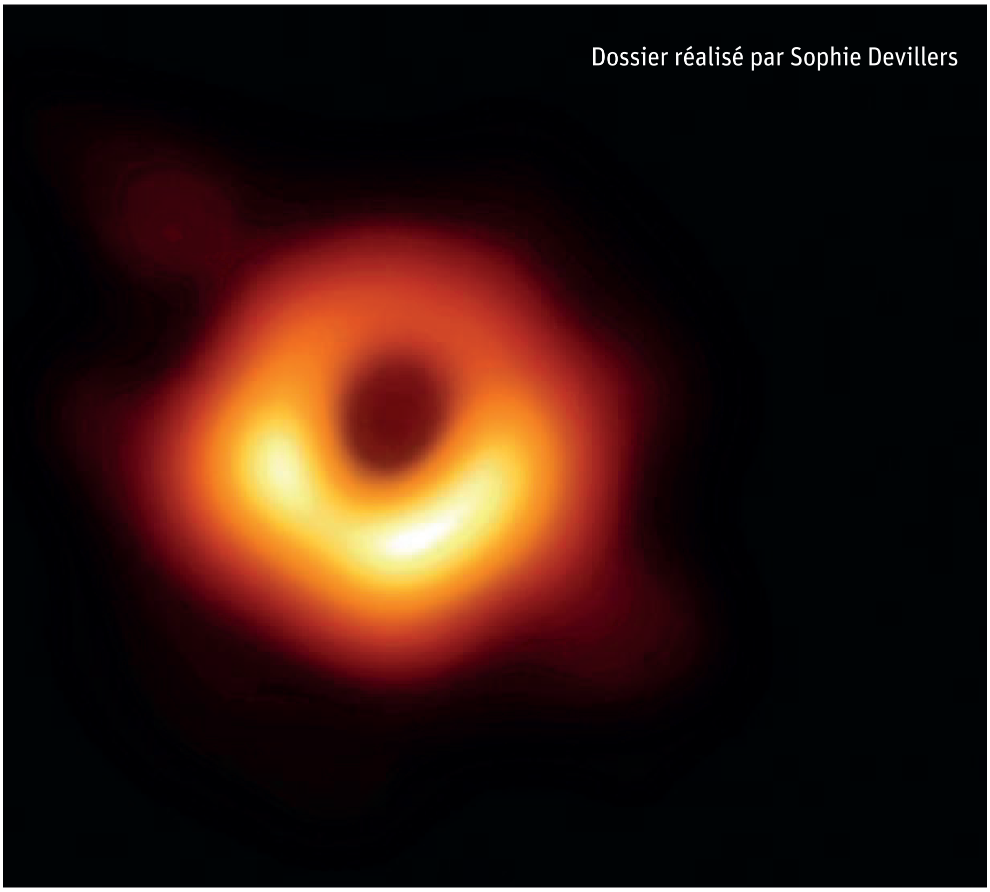
### Bambin ou ours en train d'hiberner ?

En combinant huit télescopes répartis sur le globe (Chili, Hawaï, Antarctique...), l'EHT est parvenu à créer un télescope virtuel d'environ 10 000 km de diamètre, proche de la taille de la Terre. Plus un télescope est grand, plus il permet de voir de détails.

Et les astronomes ont retenu deux cibles: les deux trous noirs, qui vus de la Terre, sont les plus gros. L'un, Sagittarius A* au centre de la Voie Lactée, à 26 000 années-lumière de la Terre. L'autre est l'un des trous noirs les plus massifs, 1 500 fois plus que Sagittarius A*. Il n'a pas de nom et est situé à 50 millions d'années-lumière de la Terre, au cœur de la galaxie M87. Mais en voyant les premiers résultats d'EHT, il a été décidé de tout focaliser sur le trou noir de M87, explique Heino Falcke. *"Le problème était que Sagittarius est mille fois plus proche, mais il tourne mille fois plus vite. Prendre une image de cette source, c'était comme prendre une photo d'un bambin, qui n'arrête pas de bouger partout. Essayez d'avoir une image stable ! Tandis que le trou noir de M87, c'était comme prendre un image d'un ours en train d'hiberner. Mille fois plus lent, il bougeait peu. C'était donc beaucoup plus facile. On prend à présent un peu plus de temps pour étudier Sagittarius."*

Les scientifiques sont aussi heureux de voir que les observations correspondent à leurs prédictions et simulations. Et que la théorie de la relativité, qui prédisait l'existence des trous noirs, passe avec cette image un nouveau test – *"un test très important"* – avec succès. *"Cela suit exactement ce qu'Einstein prédisait"*, indique Luciano Rezzolla, de l'université Goethe de Francfort. Les scientifiques attendent à présent des télescopes dans l'espace, seule solution qui permettrait d'améliorer la résolution des images des trous noirs.

Dossier réalisé par Sophie Devillers



EHT

Première image de l'ombre d'un trou noir : le trou noir supermassif du centre de la galaxie M87, observé par le réseau EHT.

## 3 QUESTIONS À

ULB

**Geoffrey Compère**
Physicien théoricien, chercheur à l'Université libre de Bruxelles

**1 Jusqu'ici, on n'avait que des images simulant ce à quoi pouvaient ressembler des trous noirs. Or, ils ont été théorisés il y a des décennies. Pourquoi était-ce si compliqué d'obtenir une première image ?**
*C'est une question de résolution d'image. C'est comme observer une puce sur la Lune. Il faut réussir à avoir un angle de vue suffisamment fin, suffisamment précis, pour arriver à en voir les détails. Pour obtenir cette première image d'un trou noir, il a fallu développer la technique de l'interférométrie à large base. Il y a plusieurs télescopes qui regardent ensemble le même endroit et les données sont combinées ensuite par des superordinateurs pour simuler un télescope unique de la taille de la Terre. Il a donc fallu développer la technique de l'interférométrie combinée entre différents télescopes. Que chaque télescope soit suffisamment puissant pour avoir une bonne résolution, et qu'il y en ait suffisamment autour de la Terre pour que cette résolution soit possible.*

**2 On peut considérer cette image comme la première observation directe d'un trou noir ?**
*Au centre de la galaxie, on sait qu'il y a un objet très compact et très noir, et on peut observer depuis de nombreuses années qu'il y a des étoiles qui orbitent autour de cet objet. Et qui orbitent tellement proches qu'il n'y a aucune autre théorie probable qu'un trou noir. Il y a aussi eu cette observation récente des ondes gravitationnelles (ondes générées par une déformation de l'espace-temps lorsque des masses voient leur énergie ou leur trajectoire modifiées, NdlR) qui sont compatibles avec la théorie d'Einstein et la collision de deux trous noirs. Cela, c'est une observation directe, mais grâce aux ondes gravitationnelles. Ici, cela va être une image via des ondes radio à haute fréquence. C'est toujours le spectre de la lumière, mais c'est en dehors du spectre visible, on ne peut pas le voir à l'œil nu, mais grâce à des instruments. Donc, c'est la première observation directe dans le spectre de la lumière. On peut ensuite reconstituer une image à partir de ces ondes radio. Dans une symphonie, on entend des sons plus aigus ou plus graves. C'est la même chose ici. D'une certaine manière, cette image d'ondes radio, on la "met" plus aiguë, et tout le monde peut la voir ; c'est un changement adapté à notre vision humaine. C'est vraiment une image de la lumière, mais notre œil ne peut pas la voir ; il faut la décaler un peu vers de plus hautes fréquences.*

**3 Au fond, à quoi cela sert-il d'avoir cette première image ?**
*C'est une première image, donc cela veut dire qu'il y en aura d'autres dans le futur, avec une meilleure résolution, dans les prochaines décennies. Elles seront beaucoup plus précises, et on pourra tester avec beaucoup plus de précision la théorie de la gravitation d'Einstein (NdlR : qui prédit l'existence des trous noirs et qui explique leur fonctionnement) en observant directement la lumière déviée par un trou noir. Ici, c'est tout d'abord une preuve directe qu'il y a un trou noir, compatible avec la théorie de la gravitation, au centre de notre galaxie et dans une galaxie proche. Cela nous permet aussi d'améliorer les connaissances de l'astrophysique des disques d'accrétion des trous noirs : comment les gaz sont happés, les phénomènes qui sont happés et déformés par le trou noir.*

# Trou noir … les astrono… photograp…

C'est un exploit rendu possible par l'alignement des huit télescopes les plus puissants du monde : le trou noir à 50 millions d'années-lumière est enfin visible.

L'image d'un trou noir : une claque pour les théories alternatives de la cosmologie. © EPA

**FRÉDÉRIC SOUMOIS**

La capture de l'image d'un trou noir est une première dans l'histoire de l'astronomie, un exploit rendu possible par l'alignement des huit télescopes les plus puissants du monde. En fait, la photo a déjà deux ans, puisque c'est en avril 2017 que les télescopes répartis à travers le monde avaient ciblé simultanément deux trous noirs, une collaboration inédite qui a abouti à la constitution d'une « antenne » virtuelle qui serait aussi large que la Terre elle-même. Ce qui permet de voir loin et mieux. De quoi capter ce qui en fait est invisible pour un œil humain.

Selon la loi de la relativité générale publiée en 1915 par Albert Einstein, qui théorise leur fonctionnement, l'attraction gravitationnelle exercée par ces monstres est telle que rien ne peut s'en échapper, ni la matière ni la lumière, quelle que soit la longueur d'onde. Résultat : ils sont invisibles.

Pour contourner ce handicap de taille, les astronomes cherchent à observer le monstre par contraste, sur la matière qui l'entoure. A proximité d'un trou noir, la lumière et la matière sont déformées, distendues de manière très intense.

Et l'image est apparue. Pas d'un seul trou noir, mais de deux. Très différents. L'un est l'un des trous noirs les plus massifs. Il n'a pas de nom et est situé à 50 millions d'années-lumière de la Terre, au cœur de la galaxie M87. C'est son image, simple et mystérieuse, qui a été rendue publique. L'autre est plus proche de nous, il s'appelle Sagittarius A*. Blotti au centre de la Voie lactée, à 26.000 années-lumière de la Terre. Sa masse est équivalente à 4,1 millions de fois celle du Soleil. Son rayon équivaut à un dixième de la distance Terre-Soleil. Son image, restée secrète, sera révélée plus tard.

Pourquoi avoir attendu deux ans pour publier ce cliché ? Parce que ce fut le temps nécessaire pour assembler les fragments épars collectés tout autour de la planète, dans une fréquence qui est hors du visible, des fréquences radio. L'image reconstituée demande donc des milliers d'heures de calculs avec les ordinateurs les plus puissants. De quoi encore laisser subsister un léger doute sur leur existence, comme le font encore quelques autres théories alternatives de la cosmologie. Qui, en fait, ce mercredi à 15 heures, ont pris un sérieux coup dans l'aile. Car les monstres noirs sont bien là où l'on pensait qu'ils étaient.

### La matière détruite par le trou noir émet une lumière détectable

Par leurs observations, les astronomes cherchent à identifier l'environnement immédiat d'un trou noir. Selon la théorie, quand la matière est absorbée par le monstre, elle émet une lumière. Le projet EHT, capable de capter les ondes millimétriques émises par l'environnement du trou noir, a pour but de définir le pourtour de l'objet céleste.

Comme on n'est pas dans un film hollywoodien, le trou noir ne fait pas de bruit (sans oxygène, il ne se transmet pas dans l'espace), ne se déplace pas mais tourne sur lui-même. Il n'est pas un grand siphon qui attirerait toute la matière pour en faire de l'antimatière. Et la Terre ne risque pas d'être engloutie par ce trou noir, puisque dans cinq milliards d'années, le Soleil, devenu une étoile rouge géante, aura fait griller nos descendants depuis longtemps.

### 30 millions d'années de voyage

Quant à faire la photo de plus près, il ne faut pas y songer. Sagittarius A* est à 30.000 années-lumière. Sans doute arrivera-t-on un jour à fabriquer un vaisseau capable d'atteindre 1 % de cette vitesse. Cela ferait 30 millions d'années pour y aller. L'être humain ne joue pas dans la même division. Et les soirées risqueraient d'être longues dans le silence absolu de l'espace.

**Geoffrey Compère.** © DR

## l'expert « Comment on se rappro…

ENTRETIEN

**FR.SO.**

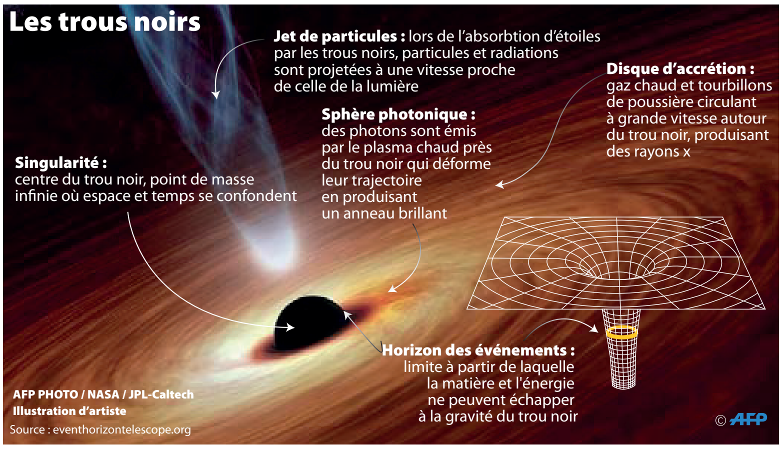
Geoffrey Compère est chercheur en physique théorique à l'Université Libre de Bruxelles (ULB)

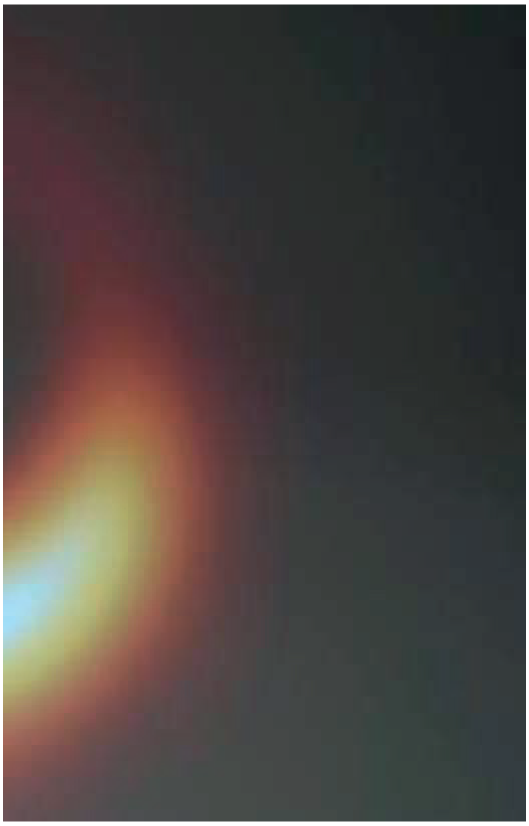
**Que nous apprend cette photo ?**

C'est une confirmation que les éléments qui étaient décrits théoriquement par Einstein et conceptualisés ensuite sont bien existants et qu'ils sont bien là où on pensait qu'ils étaient. Cela n'a l'air de rien, mais c'est une brique très importante dans le mur de la connaissance de notre univers et de notre galaxie. Au cœur de la galaxie Messier 87, il y a bien un trou noir important, M87*, à plus de 50 millions d'années-lumière de la Terre. Sa masse est équivalente à 6 milliards de fois celle du Soleil.

James Bardeen posait en 1972 la question « A quoi ressemblerait un trou noir si un spot lumineux l'éclairait par l'arrière ? » Grâce au développement de modèles d'accrétion de matière dans un trou noir, une telle image a pu être simulée pour la première fois en 1979 par Jean-Pierre Luminet, un astrophysicien au CNRS français. Et en 1999, un groupe d'astronomes a réalisé qu'il était possible de faire le cliché d'un trou noir proche, M87*, grâce à une technique révolutionnaire d'interférométrie.

**Qu'a-t-on appris de ce cliché ?**





# : comment
# ɔmes ont
# ɔhié l'invisible

## che du Big Bang »

Il y a une zone sombre au cœur de l'image, c'est l'indication de l'horizon d'un trou noir qui absorbe la lumière. Il y a un disque lumineux autour du trou noir : sa silhouette, due à la lumière happée et déviée par le trou noir. Ce disque est légèrement asymétrique : il y a plus de lumière dans le bas de l'image qu'au-dessus. L'explication est que le trou noir tourne sur lui-même ! Dans quel sens ? Dans le sens des aiguilles d'une montre quand on le regarde dans le ciel. Mais on ne connaît pas exactement son axe de rotation. Le cliché peut être expliqué de plusieurs manières, qui dépendent des détails de la matière qui entoure le trou noir. La collaboration de l'EHT a aussi photographié un autre trou noir qui est 1.500 fois plus petit et 1.000 fois moins massif : Sagittarius A*, le trou noir au cœur de notre galaxie. Son image sera diffusée bientôt. Le trou noir M87* est vorace, il absorbe beaucoup de matière. Aussi, il émet un immense jet de matière, ce qui est attribué à sa rotation très rapide. L'image obtenue corrobore cette description.

**Pourquoi avoir attendu deux ans ?**
Parce que l'analyse de données collectées est considérable. Il faut tenir compte du fait qu'il faut reconstruire des données provenant de huit télescopes différents dont un au pôle Sud. Il a fallu attendre la fin de l'hiver pour récupérer les disques durs de la station polaire. La lumière observée est dans la longueur d'onde invisible à l'œil humain, c'est une image radio à haute fréquence que l'on capte. Il faut la convertir pour qu'on puisse la « voir » effectivement avec nos yeux. La plus belle surprise des astronomes en charge a été de constater que l'image captée était totalement conforme aux prédictions.

**Ça sert à quoi ?**
Imaginez qu'un objet céleste prédit en théorie en 1915 par Karl Schwarzschild dans le cadre de la théorie d'Einstein n'était resté que théorique jusque-là. C'est d'ailleurs cela qui a permis la mise sur pied de cette mission exceptionnelle d'équipes qui se sont unies partout dans le monde pour aller plus loin. La puissance du télescope virtuel ainsi constitué est équivalente à un télescope qui aurait la taille de la Terre. Alors, certes, on n'a pas découvert quelque chose qu'on n'attendait pas, mais cette confirmation est en soi un exploit. L'idée de pouvoir simuler cette image a été émise il y a 45 ans. Il y a 20 ans, une observation potentielle de cette image a été rendue possible grâce à la construction des dispositifs d'interférométrie à base large. Cette découverte est aussi une porte ouverte à la meilleure compréhension du monde dans lequel on vit. Les trous noirs supermassifs comme M87* et celui au centre de la voie lactée, on n'en sait que peu de choses. Cela va faire avancer les connaissances en matière de gravitation. Imaginez l'émotion des gens qui ont fait ces calculs il y a 40 ans et qui voient aujourd'hui la « preuve par l'œil » que leur travail était juste ! Comprendre les lois gravitationnelles, ce n'est qu'une brique dans la connaissance de l'Univers, mais c'est une brique essentielle.

### Ce qu'on peut voir sur l'image

**Mais on voit quoi, exactement ? « Nous savons que le disque d'accrétion, la matière qui entoure le trou noir – du gaz extrêmement chaud, que nous appelons plasma, des restes d'étoiles déchiquetées par l'environnement gravitationnel – est relativement brillant. Tant qu'elle n'a pas été avalée par le trou noir, cette matière peut être détectée. L'idée était donc d'observer le trou noir par contraste », explique dit Frédéric Gueth, astronome au CNRS. « Ce que l'on voit, c'est l'ombre de la limite "de non-retour" (baptisée l'horizon des événements) du trou noir sur le disque d'accrétion brillant. L'horizon des événements est un peu plus petit que l'ombre. Et le trou noir est à l'intérieur de l'horizon des événements. »**
**Conséquence : « Ces observations ont permis de déterminer que le trou noir supermassif de la galaxie M87 avait une masse 6,5 milliards de masses solaires. »**

## HUMEUR

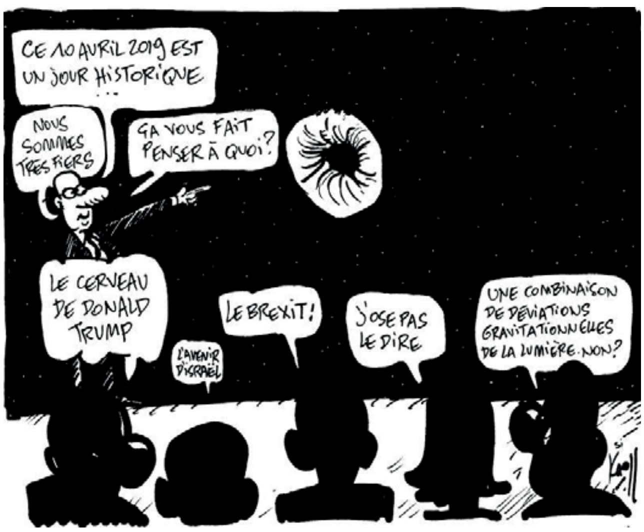
FRÉDÉRIC SOUMOIS

# Punaise, le donuts dans le trou noir

© DR

Objet mystérieux, le trou noir a inspiré les créateurs de fiction. Seuls les aînés se rappelleront du *Trou noir*, film de SF produit par Walt Disney en 1979, sombre histoire de révolte de robots autour d'un trou noir qui aspire tout. Plus émouvant, le film *Contact* (1997), de Robert Zemeckis. Et *Star Trek* en 2009. La palme de la mise en situation des dernières théories sur le trou noir dans un film de fiction revient sans conteste à l'hypnotique *Interstellar* (2014), de Christopher Nolan. Plus informatif en fait furent plusieurs épisodes des Simpsons où le physicien Stephen Hawking, spécialiste des trous noirs, apparaît. Avec la particularité que c'est Hawking qui doublait son personnage. Et que tout ce qui y est dit est correct scientifiquement. Même quand Homer rêve d'un univers en forme de donuts, en fait une authentique théorie sur l'univers. Comme quoi, la vulgarisation prend parfois des moyens très détournés…

## KROLL



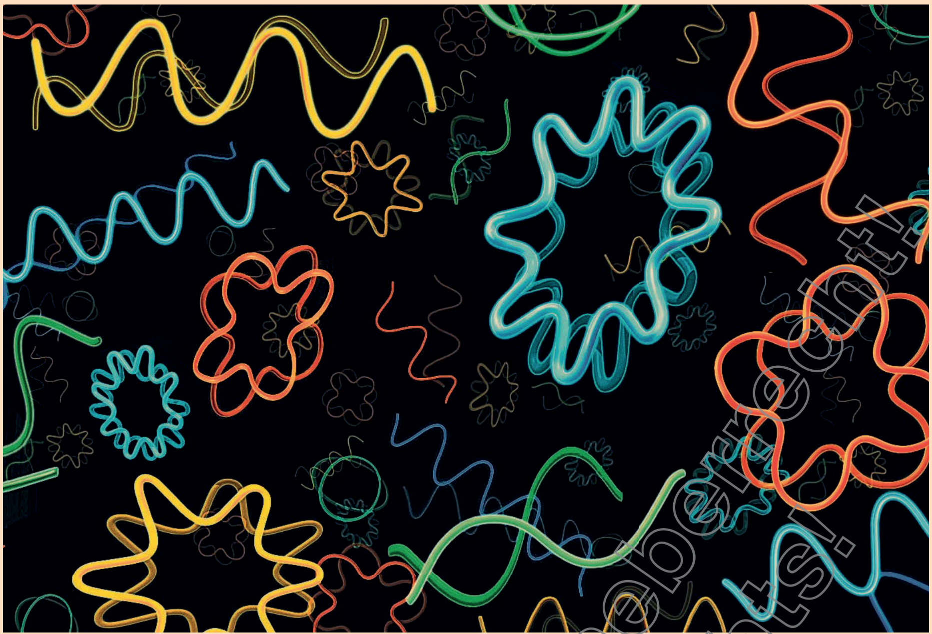


Foto: Picturedesk / Science Photo Library / Fuller

Laut der Stringtheorie besteht die Welt auf fundamentalster Ebene nicht aus Teilchen, sondern aus winzigen Fäden – den Strings.

# „Die Quantenmechanik ist wirklich verrückt"

Der belgische Physiker **Marc Henneaux** beschäftigt sich mit einer Frage, die schon Generationen an Physikern verzweifeln ließ: Wie lassen sich Quantenphysik und Relativitätstheorie zusammenbringen?

INTERVIEW: *Tanja Traxler*

Um das Universum im Großen zu beschreiben, bedienen wir uns seit über 100 Jahren der Relativitätstheorie von Albert Einstein. Die Vorgänge im Mikrokosmos gehorchen wiederum den Regeln der Quantenmechanik. Doch wie hängen die beiden Theorien zusammen? Gibt es eine Theorie, mit der sich alles abdecken lässt? Und wie könnte sie aussehen? Mit Fragen wie diesen beschäftigt sich der belgische Physiker Marc Henneaux. Kürzlich war er auf Einladung der Jungen Akademie der ÖAW und des Erwin-Schrödinger-Instituts für Mathematische Physik in Wien.

STANDARD: *Sie forschen zur wohl größten offenen Frage in der Physik – worum geht es dabei?*
**Henneaux:** Es geht darum, die Quantenmechanik mit der Relativitätstheorie zu vereinheitlichen – wir sprechen dabei von Quantengravitation. Wir wissen, dass diese Theorien in ihren jeweiligen Anwendungsfeldern sehr erfolgreich sind. Wenn wir aber versuchen, die beiden Theorien zusammenzuführen, stoßen wir auf viele Probleme. Das ist eine recht frustrierende Situation, die seit vielen Jahren anhält. Bereits in den 1930er-Jahren haben Physiker wie Wolfgang Pauli oder Werner Heisenberg erkannt, dass es schwierig sein wird, die Quantengravitation zu entwickeln. Und tatsächlich arbeiten wir fast 90 Jahre später immer noch daran.

STANDARD: *Die Relativitätstheorie beschreibt die Physik im Großen, die Quantenphysik im Kleinen – wo begegnen sich die beiden Theorien überhaupt?*
**Henneaux:** Nicht in unserer Alltagswelt, denn da sind quantenmechanische Effekte vernachlässigbar. Es gibt aber extreme Situationen, wo Relativitätstheorie und Quantenmechanik aufeinandertreffen, zum Beispiel beim Urknall oder bei Schwarzen Löchern.

STANDARD: *Welche Rolle spielt die Quantengravitation bei der Entstehung des Universums?*
**Henneaux:** Wir wissen aus Beobachtungen, dass sich das Universum ausdehnt. Wenn wir in der Zeit zurückgehen, war das Universum also immer kleiner und dichter. Um die Anfänge des Universums zu beschreiben, sind sowohl Quanten- wie auch Gravitationseffekte wichtig. Wir hoffen, dass wir durch eine Theorie der Quantengravitation den Urknall besser verstehen können und damit den Ursprung des Universums und unserer eigenen Existenz.

STANDARD: *Es gibt verschiedene Ansätze, um Relativitäts- und Quantentheorie zu vereinheitlichen. Auf welches Pferd setzen Sie?*
**Henneaux:** Wir müssen die Augen offen halten, denn wir wissen noch nicht, welche die richtige Theorie ist. Für mich ist bisher der überzeugendste Ansatz die Stringtheorie. Demnach sind die fundamentalen Elemente keine Teilchen, sondern ausgedehnte Objekte – Strings. In unseren Maßstäben sind sie allerdings so klein, dass sie wie Punkte aussehen. Die Stringtheorie gibt es schon seit vielen Jahren, und sie ist auch mit Frustration verbunden. Es konnten zwar Fortschritte erzielt werden, aber einige Fragen haben wir noch nicht beantwortet. Uns fehlen die fundamentalen Prinzipien der Stringtheorie.

STANDARD: *Bislang gibt es auch noch keine Experimente, die die Stringtheorie bestätigen. Wann könnte es so weit sein?*
**Henneaux:** Dass es keine Experimente gibt, ist eines der Probleme der Quantengravitation. Es kann für eine physikalische Theorie gefährlich sein, wenn es keine Daten gibt. Wir brauchen Tests, die zeigen, dass Einsteins Theorie nicht richtig ist, oder Experimente, die über die Reichweite dieser Theorie hinausgehen. Dafür braucht es sehr große Energien. Kurz nach dem Urknall hat es solche enormen Energien gegeben. Daher hoffen wir, dass uns Beobachtungen aus dem frühen Universum Hinweise auf die Quantengravitation liefern können. Ich mag es nicht, Vorhersagen zu machen, aber es gibt Leute, die optimistisch sind, dass wir schon in den 2030er-Jahren Daten zur Quantengravitation bekommen könnten.

STANDARD: *Welche Anhaltspunkte gibt es in der theoretischen Physik, solange keine Daten vorliegen?*
**Henneaux:** Vor allem im 20. Jahrhundert hat die Geschichte der Physik gezeigt, wie wichtig mathematische Schönheit und Konsistenz in der Physik ist. Symmetrien spielen dabei eine zentrale Rolle. Der Physiker Paul Dirac hatte dazu eine extreme Einstellung: Er sagte, wenn man zwischen zwei Theorien wählen muss, einer schönen und einer, die momentan vielversprechender aussieht, sollte man sich für die schöne Theorie entscheiden, denn letztlich wird es die richtige Theorie sein.

STANDARD: *Ist mathematische Schönheit ein zwingendes Kriterium für die Richtigkeit einer physikalischen Theorie?*
**Henneaux:** Philosophisch gesprochen würde ich sagen, nein. Aber für die Theorien, die wir kennen, funktionieren Symmetrien sehr gut, und sie waren in der Vergangenheit ein leitendes Prinzip, um Theorien zu entwickeln. Manchmal waren wir in Situationen, wo wir nicht genau verstanden haben, was vor sich geht. Mit Symmetrie-Überlegungen konnten wir wesentliche Fortschritte erzielen, die später auch experimentell bestätigt worden sind.

„Die Geschichte hat gezeigt, wie wichtig mathematische Schönheit in der Physik ist."

STANDARD: *Die Relativitätstheorie hat unser Verständnis von Raum und Zeit fundamental verändert. Was wissen wir heute darüber?*
**Henneaux:** Was die Natur von Raum und Zeit ist, dazu kann heute niemand eine fundierte Antwort geben, das ist eine der zentralen Fragen der Quantengravitation. Vor Einsteins Relativitätstheorie war die Raumzeit ein fixer Rahmen, in dem die Physik stattfindet. Dann zeigte Einstein, dass die Raumzeit kein fixes Objekt ist, sondern durch Materie gekrümmt werden kann. Die Quantenmechanik sagt uns, dass jedes dynamische Objekt fluktuiert. Das würde auch für Raum und Zeit gelten.

STANDARD: *Warum ist es Ihrer Meinung nach trotz ansprechender Anwendungen der Quantenphysik wie des Quantencomputers wichtig, die Grundlagenforschung nicht aus dem Blick zu verlieren?*
**Henneaux:** Der Physiker Niels Bohr hat einmal gesagt, wenn man nicht über die Quantenmechanik entsetzt ist, hat man sie nicht verstanden. Die Quantenmechanik ist wirklich verrückt, ich denke, dass jeder Physiker ein wenig Unbehagen sie betreffend verspürt. Viele Physiker sind daher der Meinung, dass die aktuelle Interpretation der Quantenmechanik noch nicht das letzte Wort sein kann.

**MARC HENNEAUX,** geboren 1955 in Brüssel, ist Professor an der Freien Universität Brüssel, wo er die Abteilung für Theoretische und Mathematische Physik leitet. Seit 2004 ist er zudem Direktor des renommierten Solvay-Instituts. Seine Forschung wird unter anderem vom Europäischen Forschungsrat ERC gefördert. Foto: Solvay-Institut

Un nid de célèbres scientifiques se réunissent à Bruxelles. On se croirait à hôtel Métropole en 1911 où Currie, Einstein ou encore Poincaré s'étaient retrouvés. © BRIDGEMAN IMAGES.

# L'esprit de Solvay plane sur la Belgique

500 spécialistes sont rassemblés autour de la théorie des cordes. Hommage à Mimi Solvay, mécène depuis… 65 ans.

FRÉDÉRIC SOUMOIS

Ne le dites pas aux ennemis de la science : il y a depuis ce lundi un véritable nid de scientifiques de très haut niveau rassemblés pour un congrès autour de la théorie des cordes (ce mardi à Bozar), mais aussi pour rendre hommage à une mécène d'exception, Mimi Solvay. Celle-ci soutient financièrement et moralement les conférences internationales Solvay depuis… 65 ans. Entourée de ses petits-enfants, mais aussi de David Gross, Prix Nobel de physique 2004, Kurt Wüthrich, Prix Nobel de chimie 2002, Lars Brink, ancien président du jury Nobel de physique, Thomas Hertog, le « dernier étudiant » de Stephen Hawking. Et puis « notre » Nobel aussi, François Englert, à qui tous rendent hommage.

Mis à part la tenue, plus décontractée, et la présence (à peine) plus importante de femmes, on pourrait se croire en ce jour de 1911 où Ernest Solvay fut le mécène et organisateur des toutes premières conférences qui portaient son nom. Réunis au célèbre hôtel Métropole, les chercheurs de l'époque incarnaient l'excellence dans ce domaine : Marie Curie, Henri Poincaré, Ernest Rutherford ou encore Albert Einstein. Solvay figure aussi sur le cliché, mais il n'était pas là, il a été rajouté ensuite. C'est que l'homme, qui avait lui-même ses théories plutôt élaborées sur la physique, aimait côtoyer ces grands de la pensée, mais ne se confondait pas avec eux. Jusqu'en 1922, date de sa disparition, il veilla de près à la qualité des personnalités invitées et des débats qui suivaient les présentations centrées autour d'un thème. C'est ainsi qu'à la liste trop allemande de Lorenz, le premier président scientifique, lui-même Nobel, il fait ajouter Marie Curie et Poincarré. Le comité scientifique gardera son flair. Comme le rappelle Marc Henneaux, professeur à l'ULB et directeur des Instituts internationaux de physique et de chimie Solvay, en 1954, lors du congrès de physique auquel contribua Mimi Solvay, il y avait 26 participants. Pas moins de sept recevront le prix Nobel dans les années qui suivront.

**L'action de Solvay, déterminante ?**

Chaque organisation des Instituts Solvay rappelle et incarne le rôle joué par Ernest Solvay dans le développement de l'esprit scientifique. « Par son mécénat d'une ampleur inégalée en Belgique, Solvay est un acteur clé de l'institutionnalisation des sciences dans son pays natal, mais aussi à l'international », soulignent ses historiographes. Il confie au médecin Paul Héger (président du conseil d'administration de l'ULB) la mission de développer un Institut de physiologie à partir de 1885, alors que l'ingénieur Emile Waxweiler est le grand organisateur de l'Institut de sociologie Solvay (1902) et de l'Ecole de commerce Solvay (1903). Ces trois instituts, implantés au cœur de la « cité scientifique du parc Léopold de Bruxelles », seront ensuite rattachés à l'ULB.

L'action de Solvay, industriel richissime mais mécène attentif et passionné, fut-elle déterminante ? On peut le croire quand on voit ce que ces conseils ont pesé à une époque où le rassemblement de scientifiques n'était pas aussi fréquent qu'aujourd'hui. Les conseils vont être le berceau de plusieurs révolutions de la physique, notamment en ce qui concerne la physique quantique.

Einstein participe, dès 1911, à ces fameux conseils et y joue un rôle prépondérant. Ceux auxquels il participe sont le théâtre de la « révolution quantique » : les discussions de Bruxelles ponctuent les étapes successives de cette révolution. Elles auront un profond impact sur les travaux et la pensée d'Einstein, principalement sur son attitude vis-à-vis de la mécanique quantique. De retour à Prague (après le conseil de 1911), Einstein ne se contente pas de développer sa théorie de la gravitation. Il tient aussi à élucider le mystère soulevé par son hypothèse des quanta de lumière. Il montre dès 1912 que cette hypothèse est en accord avec les principes généraux de la thermodynamique. Il n'en reste pas moins conscient de la difficulté de concilier ces quanta avec le caractère ondulatoire de la lumière.

La présence d'Einstein au premier conseil de physique a aussi fortement contribué à faire reconnaître son génie par les plus éminents physiciens de l'époque, et en particulier par les deux « gloires » de la science allemande : Max Planck et Walther Nernst, qui sont étroitement associés aux débuts des conseils Solvay et de l'Institut international de physique Solvay (IIPS) créé en 1912.

## Le futur collisionneur circulaire du Cern né à Bruxelles

**La semaine dernière, plus de 500 physiciens de haut vol venus de la planète entière se sont réunis à Bruxelles pour prendre une série de décisions concernant l'avenir du futur collisionneur circulaire (FCC) du Cern. Unique au monde, il sera construit à la frontière entre la Suisse et la France, tout près de l'actuel « Large Hadron Collider » (LHC) qui a permis de vérifier l'existence expérimentale du boson scalaire de Brout, Englert et Higgs, valant ensuite le prix Nobel aux deux derniers.**

**Le nouveau collisionneur aura une longueur de 100 kilomètres, soit quatre fois plus que son prédécesseur. Constitué d'aimants supraconducteurs à champ élevé de nouvelle génération, il offrira toute une gamme de possibilités en matière de physique : l'étude de la manière dont un boson scalaire interagit avec un autre boson scalaire ou l'exploration approfondie du rôle de la brisure de symétrie électrofaible dans l'histoire de notre univers… Il pourrait également permettre aux scientifiques d'accéder à des échelles d'énergie sans précédent et d'y chercher de nouvelles particules massives, ce qui ouvrirait de multiples perspectives pour de grandes découvertes. De plus, cette machine pourrait aussi faire entrer en collision des ions lourds. Et permettrait d'étudier l'état où se trouvait la matière dans l'univers primordial.**

**Le futur collisionneur circulaire réalisera aussi des collisions électron-positon, proton-proton et ion-ion à des énergies et des intensités sans précédent, avec la possibilité de collisions électron-proton et électron-ion.**

**Plus puissant que le « Large Hadron Collider », il devrait fournir de nouvelles informations sur l'origine de l'univers. La découverte du boson de Brout, Englert et Higgs a ouvert une autre voie à la recherche, dans la mesure où cette particule pourrait représenter une passerelle vers une nouvelle physique.**

**La réalisation d'études détaillées des propriétés du boson est par conséquent une priorité pour tout futur accélérateur destiné à la physique des hautes énergies. Or les différentes options envisagées par l'étude FCC offrent des possibilités exceptionnelles à cet égard. Par ailleurs, pour répondre à des questions telles que la nature de la matière noire ou la prépondérance de la matière sur l'antimatière, une physique au-delà du modèle standard est nécessaire.** FR.SO

# OVERVIEW OF THE INSTITUTES

## THROUGH SELECTED DATA

### THE 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 |
| 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 |

### CHAIRS OF THE INTERNATIONAL SCIENTIFIC COMMITTEE FOR PHYSICS

**since the first Solvay Conference on Physics**

| | |
|---|---|
| 1911 - 1928 | Hendrik Lorentz<br>1902 Nobel Laureate in Physics, Haarlem (The Netherlands) |
| 1928 - 1946 | Paul Langevin, Paris (France) |
| 1946 - 1962 | Sir Lawrence Bragg<br>1915 Nobel Laureate in Physics, Cambridge (UK) |
| 1962 - 1967 | Robert Oppenheimer<br>Princeton (USA) |
| 1967 - 1968 | Christian Møller, Copenhagen (Denmark) |
| 1969 - 1980 | Edoardo Amaldi, Rome (Italy) |
| 1980 - 1990 | Léon Van Hove, Genève (Switzerland) |
| 1992 - 2006 | Herbert Walther, Munich (Germany) |
| 2006 - present | David Gross<br>2004 Nobel Laureate in Physics<br>Santa Barbara (USA) |

## THE 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 Hormons |
| 1947 | Isotops |
| 1950 | Oxidation mechanism |
| 1953 | Proteins |
| 1956 | Some problems in mineral chemistry |
| 1959 | Nucleoproteins |
| 1962 | Energy transfer in gases |
| 1965 | Reactivity of the Photoexited 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 Noncovalent 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 |

## CHAIRS OF THE INTERNATIONAL SCIENTIFIC COMMITTEE FOR CHEMISTRY

**since the first Solvay Conference on Chemistry**

| | |
|---|---|
| 1922 - 1939 | Sir William Pope, Cambridge (UK) |
| 1945 - 1958 | Paul Karrer, 1937 Nobel Laureate in Chemistry, Zurich (Switzerland) |
| 1958 - 1988 | Alfred Ubbelohde, London (UK) |
| 1989 - 2011 | Stuart Rice, Chicago (USA) |
| 2011 - present | Kurt Wüthrich, 2002 Nobel Laureate in Chemistry, Zurich (Switzerland) and La Jolla (USA) |

# THE INTERNATIONAL SOLVAY CHAIRS IN PHYSICS AND IN CHEMISTRY

## JACQUES SOLVAY CHAIR IN PHYSICS

| | |
|---|---|
| 2006 | Ludwig Faddeev, Saint-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 |

## SOLVAY CHAIR IN CHEMISTRY

| | |
|---|---|
| 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 |
| 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 | Ben Feringa, 2016 Nobel Laureate University of Groningen The Netherlands |
| 2019 | Gernot Frenking, Philipps-Universität Marburg, Germany |

## 2011 SOLVAY CENTENARY CHAIR

David Gross, Santa Barbara, USA
2004 Nobel Laureate in Physics

# 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 |

# THE 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 21st 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

20 October 2013

"How proteins are made in the cell: Visualizing the ribosome in action"

by Joachim Frank (Columbia University, USA)

"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 (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)

"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 Medecine

"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)

"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)

# COLOPHON

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## Postal address

International Solvay Institutes
Campus Plaine ULB / CP 231
Bd du Triomphe
B-1050 Brussels | Belgium

## Delivery and visiting address

International Solvay Institutes
Campus Plaine ULB / Access 2
Bd de la Plaine
Building N.O.
5th Floor - Office 2N5 105A
B-1050 Brussels | Belgium




| | |
|---|---|
| Ms Bogaerts: | + 32 2 650 55 42<br>dominique.bogaerts@ulb.ac.be |
| Ms Van Geet: | + 32 2 650 54 23<br>isabelle.vangeet@solvayinstitutes.be |
| Website: | www.solvayinstitutes.be<br>Webdesigner: Thomas Philippe<br>Webmaster: Isabelle Van Geet |