2020
ANNUAL REPORT

INTERNATIONAL SOLVAY INSTITUTES BRUSSELS

Instituts Internationaux de Physique et de Chimie fondés par Ernest Solvay asbl
Internationale Instituten voor Fysica en Chemie gesticht door Ernest Solvay vzw

2020

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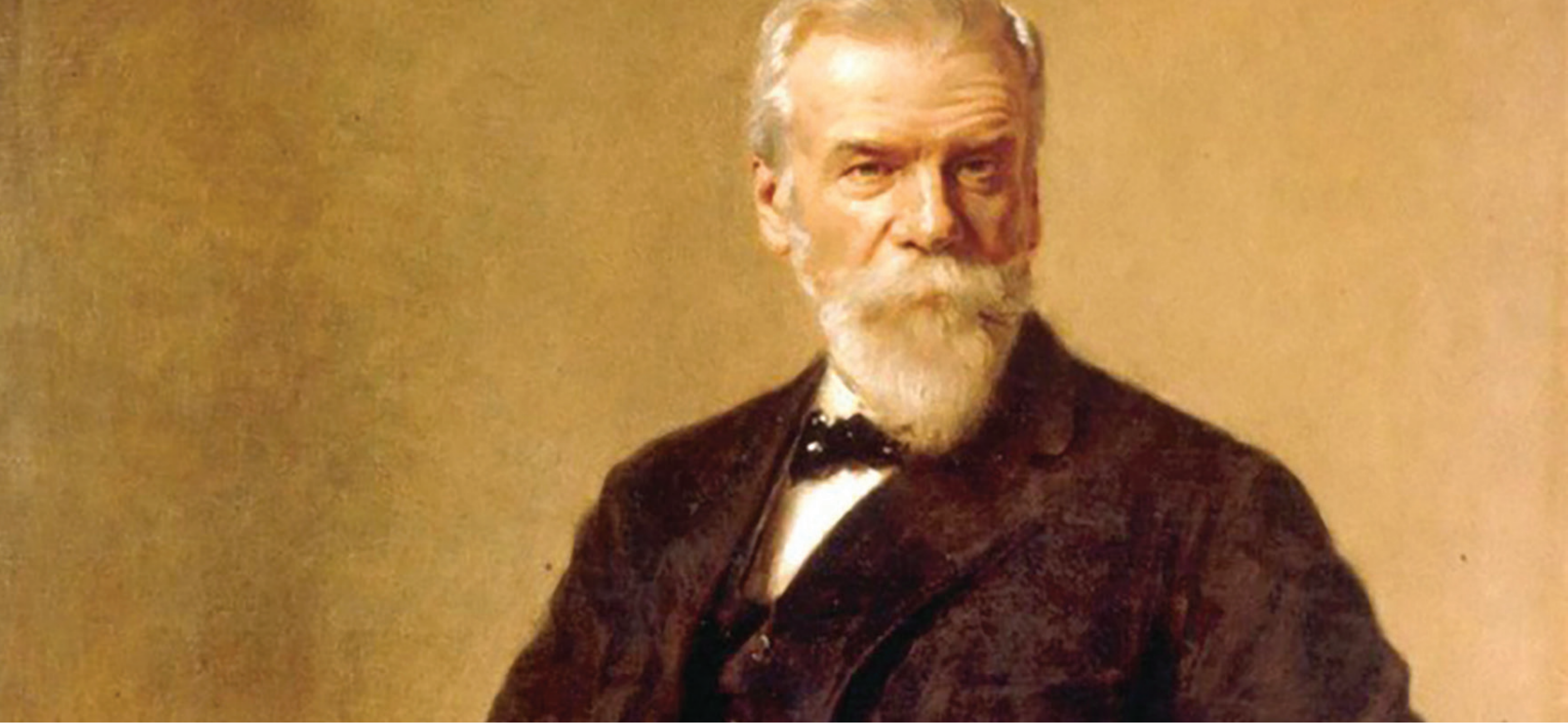

THERE ARE NO LIMITS TO WHAT

ERNEST SOLVAY

SCIENCE CAN EXPLORE

THE INTERNATIONAL SOLVAY INSTITUTES FOUNDED BY ERNEST SOLVAY, ACKNOWLEDGE WITH GRATITUDE THE

THE SOLVAY FAMILY

FOR PHYSICS AND CHEMISTRY,

GENEROUS SUPPORT OF

SOLVAY

Progress beyond

RICHTING MORGEN
MET WETENSCHAP, TECHNOLOGIE, CREATIVITEIT & INNOVATIE

Met steun van de
Vlaamse overheid

FÉDÉRATION
WALLONIE-BRUXELLES

be.brussels


STED
MINFLUX
PALM/STORM
1 nm
10 nm

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.

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A WORD FROM THE PRESIDENT

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

It has been an interesting year!

It is as if we have been suspended in time. And much of what we normally do: bring people together, has been relegated to later (when things get back to normal?). Not knowing of course, when that will be. So, it has been a year of living with utter uncertainty: will travelling be allowed? Will the speakers take the risk to come to Brussels? Will they meet our students? …

Luckily technology was able to jump right in and we discovered convenient digital tools that made it possible to keep interacting in order to manage the uncertainty.

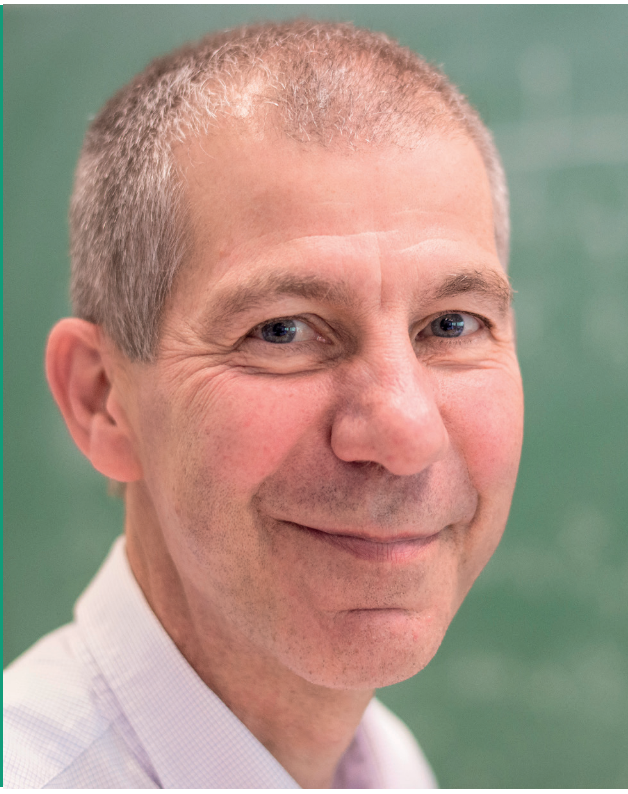
Science is all about sharing great ideas. Although scientific meetings can be held on Zoom or Teams, the real exchanges typically happen around a cup of coffee, at a dinner table or during a walk in a great square, in the city of Brussels. Meeting new people, traveling and being in a foreign land promotes new ways of looking at problems together. This is what the Solvay Institutes have done well for nearly 110 years. We stand ready to continue for another hundred years and we look forward to when we can again, bring together leading scientists in their incarnated form to confront their ideas with passion. In the meantime, much is being done to deliver to our scientific community an outstanding program for the next two years, culminating with the 100 year anniversary of the first chemistry conference in October 2022. We certainly hope to see you there!

My most grateful thanks go to the director and his team that have not stood idle during these covid times. Research and administrative duties were carried out with the same sense of purpose and excellence that is theirs.

I am also grateful to our sponsors, the ULB and the VUB universities, the Solvay Company, the Belgian National Lottery, the Brussels-Capitale Region, the Fédération Wallonie-Bruxelles, the Vlaamse Regering, the Solvac Company and the very supportive Solvay family.

Jean-Marie Solvay | President

A WORD FROM THE DIRECTOR



The pandemic that is shaking the world did not spare the International Solvay Institutes in 2020. Our "core business" is to organize scientific meetings where researchers physically convene to discuss their most recent work.The impact of the sanitary crisis on our activities was therefore inescapable.

Our policy for handling this unprecedented situation has been to postpone – rather than cancel - most of our 2020 on-site meetings to 2021 and 2022. Only three workshops and two colloquia could take place before the start of the pandemic or were maintained in virtual form. The other activities planned for 2020 have been rescheduled. The new calendar is given in the table below.

While this new schedule will lead to an extra logistical burden, it is scientifically manageable because there is no duplicate with the activities originally planned for 2021 and 2022, which have been maintained. This absence of duplication reflects the breadth of our activities, which cover a broad spectrum of research lines in chemistry, physics and allied fields.

We are fully aware that the pandemic is not over and that further adjustments in our program might be needed (in fact, the first two workshops of 2021 have already been rescheduled to 2022). But it does not appear unreasonable to hope that by July of 2021, "face-to-face" activities will progressively resume, most likely in hybrid form at the beginning.

While the pandemic has forced us to temporarily suspend our on-site activities, we did not remain inactive. On the contrary, like nature preparing for the Spring season, we have been engaged on several fronts. We have invested in human capital by granting more financial support to young researchers. We have pursued the systematic filing (and exploration!) of our archives, which constitute a true treasure concealing unique documents of wide interest. And we have also invested in the infrastructure by remodeling the Solvay lecture room, which is now equipped with up-to-date modern videoconference technology – an initiative that will be most welcome if we must restart our meetings in hybrid form.

On the publication side, the release in 2020 of four books should be particularly commended.

First, the proceedings of the 27th Solvay Conference on Physics "The Physics of Living Matter: Space, Time and Information in Biology" (2017) and the proceedings of the 25th Solvay conference on Chemistry "Computational Modeling: from Chemistry to Materials to Biology" (2019) both appeared. These two volumes cover not only the contributions to the respective conferences but also the ensuing scientific discussions. Getting vivid oral interactions in publishable written format requires much careful editorial work. I would like to praise Professor Alexander Sevrin (for the physics volume) and Professors Anne De Wit and Laurence Rongy (for the chemistry volume) who successfully supervised this difficult task. Also to be applauded is the fact that the proceedings of the chemistry conference were produced in a record time.

Second, two remarkable books on the history of the Solvay Institutes have been published, "Fantaisies quantiques" by Catherine d'Oultremont and Marina Solvay and "La singulière histoire des premiers Conseils Solvay" by Franklin Lambert et Frits Berends. These books provide complementary accounts of the fascinating early days of the Institutes and are rich of new information and many previously unreleased anecdotes. A beautiful advertisement for the Institutes and a reading to be highly recommended!

The 2020 report describes all these developments, as well as the activities that did take place in 2020. A significant fraction of the report is devoted to the research of the scientists connected with the Institutes, reflecting our action at this level.

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.

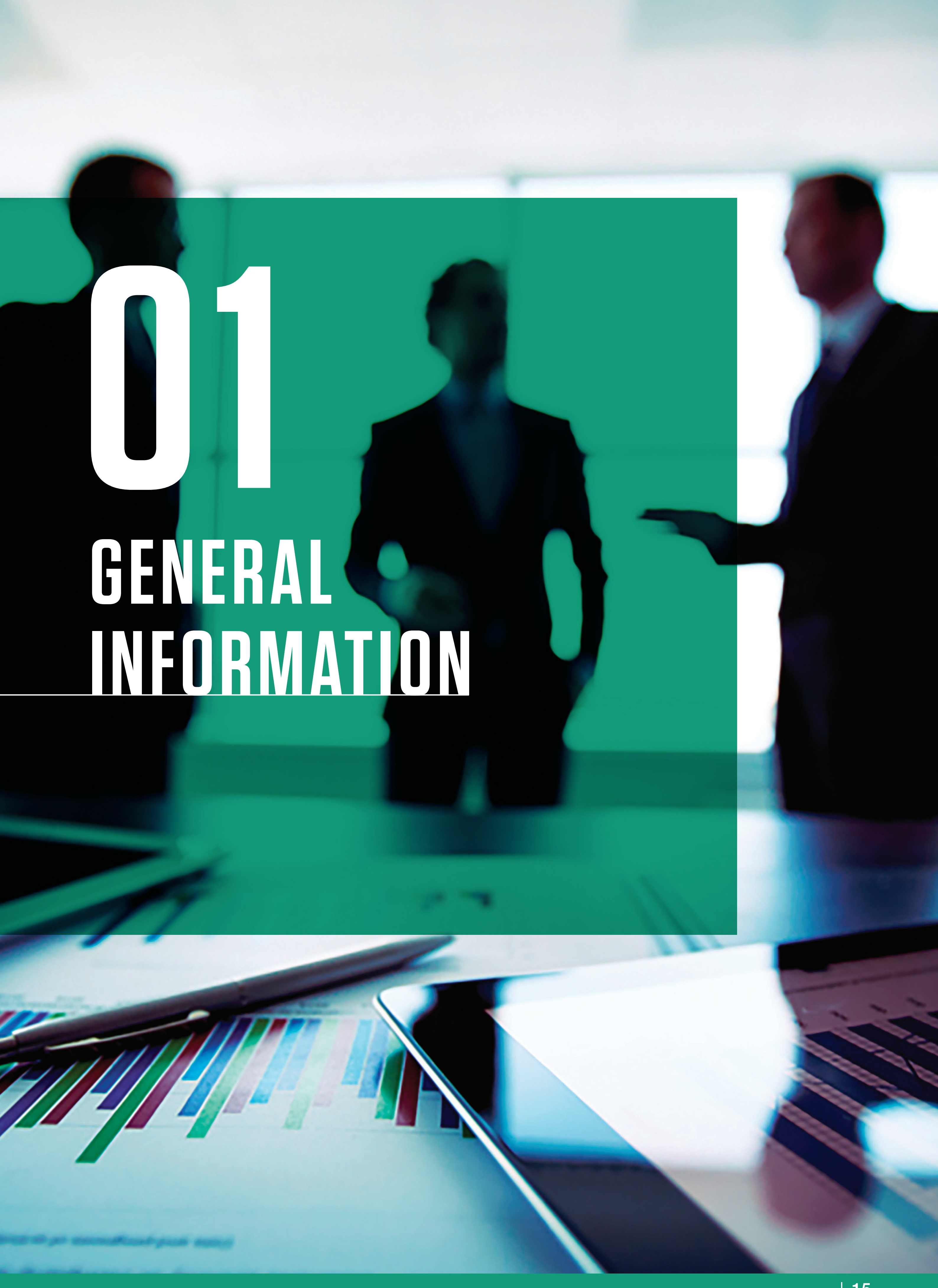
I would also like to express our gratitude to the faithful sponsors of the Institutes, which are the Université Libre de Bruxelles, the Vrije Universiteit Brussel, the Solvay Company, the Belgian National Lottery, the Brussels-Capitale Region, the Fédération Wallonie-Bruxelles, the Vlaamse Regering, the Solvac holding, and last but not least – and as just recalled –, 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 Institutes has been key in navigating through these difficult times and is again gratefully acknowledged.

Marc Henneaux | Director

CALENDAR OF RESCHEDULED SOLVAY ACTIVITIES

ACTIVITY	ORIGINAL DATES	RESCHEDULED DATES
2020 Solvay Chair in Physics Professor R. Blandford	Fall of 2020	11, 15, 19, 23, 24 March 2021 (online) Closing lecture in October of 2021
2020 Solvay Chair in Chemistry Professor J. Aizenberg	Fall of 2020	22, 29 April - 6, 20 May 2021 (online) Closing lecture in the Fall of 2021
Workshop on “Cosmological Frontiers in Fundamental Physics 2020”	26 - 29 May 2020	25 - 28 May 2021
Workshop in memory of Prof. Grégoire Nicolis on “Nonlinear phenomena and complex systems”	11 - 13 May 2020	14 - 16 June 2021 (online)
2020 New Horizons Lectures in Physics Professor D. Stanford	12 - 17 October 2020	8, 11, 15 June 2021 (online) Closing lecture in October of 2021
Workshop on “Quantum Chemistry meets Quantum Information”	13 - 16 July 2020	13 - 16 July 2021
2020 New Horizons Lectures in Chemistry Professor H.-J. Wörner	26 - 30 October 2020	5, 12, 19 September 2021 (online) Closing lecture in the Fall of 2021
2020 Public Event at Flagey	18 October 2020	12 September 2021
2021 Public Event at Flagey	24 October 2021	24 October 2021
Workshop on “Quantum Simulation 2021”	8 - 11 February 2021	7 - 9 February 2022
2021 Solvay Chair in Physics Professor J. Dalibard	February 2021	February 2022
Workshop on “New Ways to do Chemistry”	28 - 30 April 2021	25 - 27 April 2022
28th Solvay Conference on Physics	14 - 17 October 2020	19 - 21 May 2022
Workshop on ”Nucleation: multiple pathways multiple outcomes”	4 - 6 November 2020	7 - 9 December 2022



01 GENERAL INFORMATION

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| Chairman of the Board of Directors of the Solvay Group

OF DIRECTORS

Eddy Van Gelder
| Chairman of the Board of Directors of the VUB

Pierre Gurdjian
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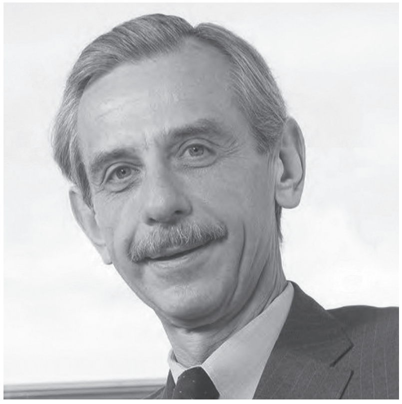
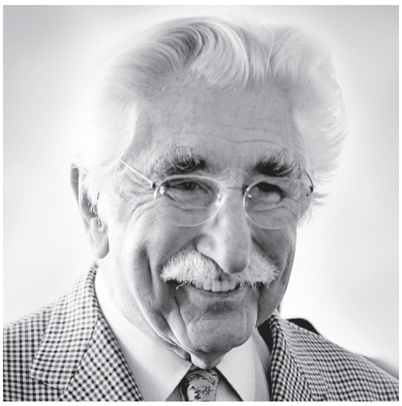


Eric Boyer de la Giroday
| Honorary Chairman of the Board of Directors ING Belgium sa/nv

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



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| Former Chairman of the Board of Directors of the Solvay Group

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Former Deputy Director for Chemistry of the Solvay Institutes

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Director

Professor Alexander Sevrin | VUB
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

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Professor VUB
Deputy Director for Chemistry

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Professor ULB
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Freddy Dumortier
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Professor ULB | Director

Franklin Lambert
Emeritus Professor VUB

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

Marina Solvay
Chairwoman of the Archives Committee of the Solvay Institutes

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

AND STAFF

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
- Mr Tahar Hmida
  Accounting officer

INTERNATIONAL SCIENTIFIC

CHAIR

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

SCIENTIFIC SECRETARY

Professor Alexander Sevrin
Vrije Universiteit Brussel, Belgium

INTERNATIONAL SCIENTIFIC

CHAIR

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

SCIENTIFIC SECRETARY

Professor Anne De Wit
Université Libre de Bruxelles, Belgium

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.

COMMITTEE FOR PHYSICS

MEMBERS

Professor Roger Blandford
Stanford University, USA

Professor Steven Chu
1997 Nobel Laureate
Stanford University, USA

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Professor Fabiola Gianotti
CERN, Switzerland

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Professor Wolfgang Ketterle
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Professor Peter Zoller
University of Innsbruck, Austria

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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

Professor JoAnne Stubbe
Massachusetts Institute of Technology, USA

Professor Bert Weckhuysen
University of Utrecht, The Netherlands

Professor George M. Whitesides
Harvard University, USA

INTERNATIONAL

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.

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Professor Lars Brink

Chalmers University of Technology, Göteborg, Sweden

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Professor Marc Henneaux
ULB, Brussels

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VUB, Brussels

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Professor Sophie Hermans I UCL, Louvain
Professor Roberto Lazzaroni I UMONS
Professor Luc Moens I UGent
Professor Jean-Christophe Monbaliu I ULg, Liège
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Professor Marlies Van Bael I UHasselt

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Professor Marc Henneaux I ULB, Brussels

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Ecole Normale Supérieure, Paris, France

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2013 Nobel Laureate
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1999 Nobel Laureate
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Former CEO Solvay Group, Belgium

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2006 Nobel Laureate
Stanford University, USA

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1987 Nobel Laureate
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Moscow State University, Russia

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

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Croonenberghs Olivier
Defourny Michel
De Keuleneer Eric
Desmet Gert
De Vos Gabrielle
De Wit Anne
Dumortier Freddy
Englert Yvon
Gaspard Pierre
Geerlings Paul
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Belgium

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

IN MEMORIAM

The International Solvay Institutes mourn the passing away of four honorary members in the last three years:

George Sudarshan (13 May 2018)
Manfred Eigen (6 February 2019)
Mario Molina (7 October 2020)
Isaak Khalatnikov (9 January 2021)

Viacheslav Belyi, long-time collaborator of the International Solvay Institutes since 1982, also passed away in 2020. Remarkable scientist, Slava was an active collaborator of Ilya Prigogine. He regularly visited the Institutes, where his warm friendship was appreciated by all.

We will deeply miss them.

ASSEMBLY

de Maret Pierre
Misonne Jean-François
Pauwels Caroline
Piret Jean-Marie
Querton Alain
Querton Cédric
Rolin Olivia
Rolin Patrick
Sanglier Michèle
de Selliers de Moranville Jacques
Sevrin Alexander
Madame Solvay de La Hulpe
Solvay Anne-Christine
Solvay Carole
Solvay Denis
Solvay Jean-Marie
Solvay Marina
Van Camp Benjamin
Van Gelder Eddy
Vanherweghem Jean-Louis
Veretennicoff Irina
Viviers Didier
Wyns Lode
Wielemans Patrick
Willems Hans
Willox Ralph

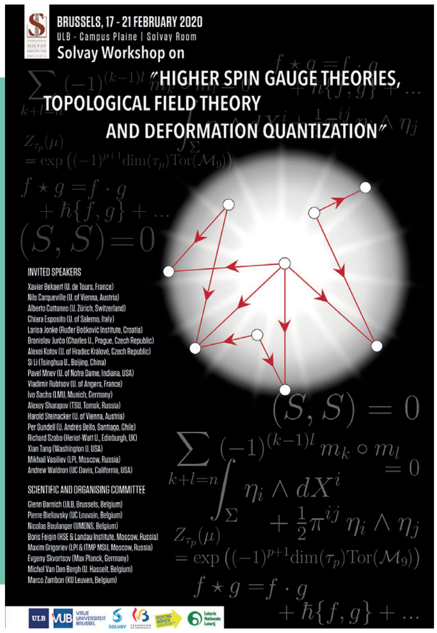
02

WORKSHOPS AND SCHOOLS

WORKSHOP ON

"HIGHER SPIN TOPOLOGICAL FIELD DEFORMATION

17 - 21 FEBRUARY 2020



Over the recent years several fascinating connections have been discovered between Higher Spin gauge theories, Deformation Quantisation and Topological Field Theory. As it often happens, many concepts and structures are independently (re)discovered by mathematicians and theoretical physicists from different perspectives.

The workshop was designed to bring together, for the first time, leading experts in these fields so as to foster cross-fertilization of ideas between the communities and trigger the production of new lines of research.

Topics as diverse as homotopy Lie algebras, non-commutative geometry, matrix models, defects in topological field theory, quantization of orbifolds and higher spin gauge fields, were intensively discussed by the participants.

GAUGE THEORIES, THEORY AND QUANTIZATION 2

SCIENTIFIC AND ORGANISING COMMITTEE

Glenn Barnich (ULB, Brussels, Belgium)
Pierre Bieliavsky (UCL, Louvain, Belgium)
Nicolas Boulanger (UMONS, Belgium)
Boris Feigin (HSE & Landau Institute, Moscow, Russia)
Maxim Grigoriev (LPI & ITMP MSU, Moscow, Russia)
Evgeny Skvortsov (Max Planck, Germany)
Michel Van Den Bergh (UHasselt, Belgium)
Marco Zambon (KU Leuven, Belgium)

INVITED SPEAKERS

Xavier Bekaert (U. de Tours, France)
Pierre Bieliavsky (UCL, Louvain, Belgium)
Nils Carqueville (U. of Vienna, Austria)
Alberto Cattaneo (U. Zürich, Switzerland)
Chiara Esposito (U. of Salerno, Italy)
Larisa Jonke (Ruđer Bošković Institute, Croatia)
Branislav Jurčo (Charles U., Prague, Czech Republic)
Alexei Kotov (U. of Hradec Králové, Czech Republic)
Vladimir Rubtsov (U. of Angers, France)
Ivo Sachs (LMU, Munich, Germany)
Peter Schupp (Jacobs U., Bremen, Germany)
Alexey Sharapov (TSU, Tomsk, Russia)
Harold Steinacker (U. of Vienna, Austria)
Per Sundell (U. Andrés Bello, Santiago, Chile)
Richard Szabo (Heriot-Watt U., Edinburgh, UK)
Xian Tang (Washington U. USA)
Mikhail Vasiliev (LPI, Moscow, Russia)
Andrew Waldron (UC Davis, California, USA)

PROGRAMME

Monday 17 February 2020

Welcome by Marc Henneaux (Director of the Solvay Institutes, Brussels)

Ivo Sachs	*From BV-Quantisation To Homotopy Algebras And Back*
Xavier Bekaert	*Introduction to higher-spin gravity*
XiangTang	*Dunkl Operators and Quantization of Orbifolds*
Discussion	

Tuesday 18 February 2020

Chiara Esposito	*Twisting procedure and formality theorem*
Alexei Kotov	*Gauge PDEs: the geometry of local gauge theories*
Alexey Sharapov	*Noncommutative Deformation Quantization and Gauge Interactions*
Branislav Jurčo	*Homotopy Algebras in SFT*
Discussion	

Wednesday 19 February 2020

Alberto Cattaneo	*The BV-BFV formalism*
Richard Szabo	*Homotopy Lie algebras for gravity and their braided deformations*
Peter Schupp	*Graded Geometry and Gravity*
Larisa Jonke	*Courant algebroid and Lie_infinity algebras*
Discussion	

Thursday 20 February 2020

Mikhail Vasiliev	*Spin-locality and star-product functions in higher-spin theory*
Per Sundell	*Topological fields, noncommutative geometries and higher spins*
Vladimir Rubtsov	*Quantum uniformisation and Calabi-Yau algebras*
Pierre Bieliavsky	*Universal Deformation Formulae*
Discussion	

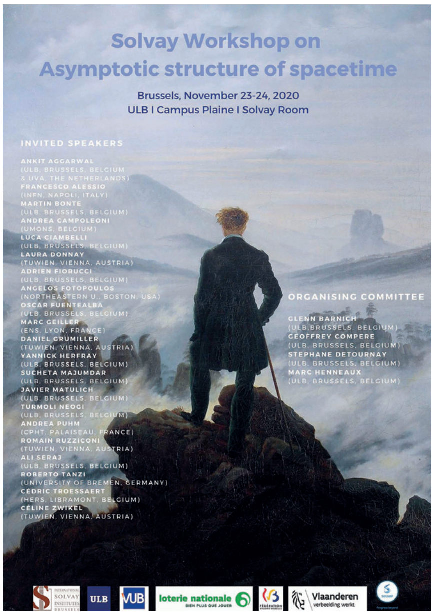
Friday 21 February 2020

Nils Carqueville	*Defects in topological quantum field theory*
Harold Steinacker	*Higher spin gauge theory, matrix models, and the quantum structure of space-time*
Andrew Waldron	*Quantization from Contact Geometry*

WORKSHOP ON

“THE ASYMPTOTIC

23 - 24 NOVEMBER 2020 – ONLINE



One of the lessons that has been learned from the study of the behavior of the gravitational field at infinity is that the algebra of asymptotic symmetries can be much larger than the algebra of background isometries.

The first instance where this phenomenon was observed was four-dimensional Einstein gravity with a vanishing cosmological constant, where studies at null infinity revealed that the asymptotic symmetries formed the infinite-dimensional Bondi-van der Burg-Metzner-Sachs (BMS) algebra, which can even be further extended to include super-rotations. Another much studied example is anti-de Sitter gravity in three spacetime dimensions, where the asymptotic symmetry algebra is given, for standard AdS boundary conditions, by two copies of the infinite-dimensional Virasoro algebra. In both cases, the asymptotic symmetry algebra contains the algebra of background isometries (the Poincaré algebra or the anti-de Sitter algebra, respectively), but is strictly bigger than it. Furthermore, a non-trivial central charge with interesting physical significance may appear in the Poisson bracket algebra of the generators of the asymptotic symmetries - which is necessarily trivial for the subalgebra of background isometries -, as it is the case for three-dimensional AdS gravity.

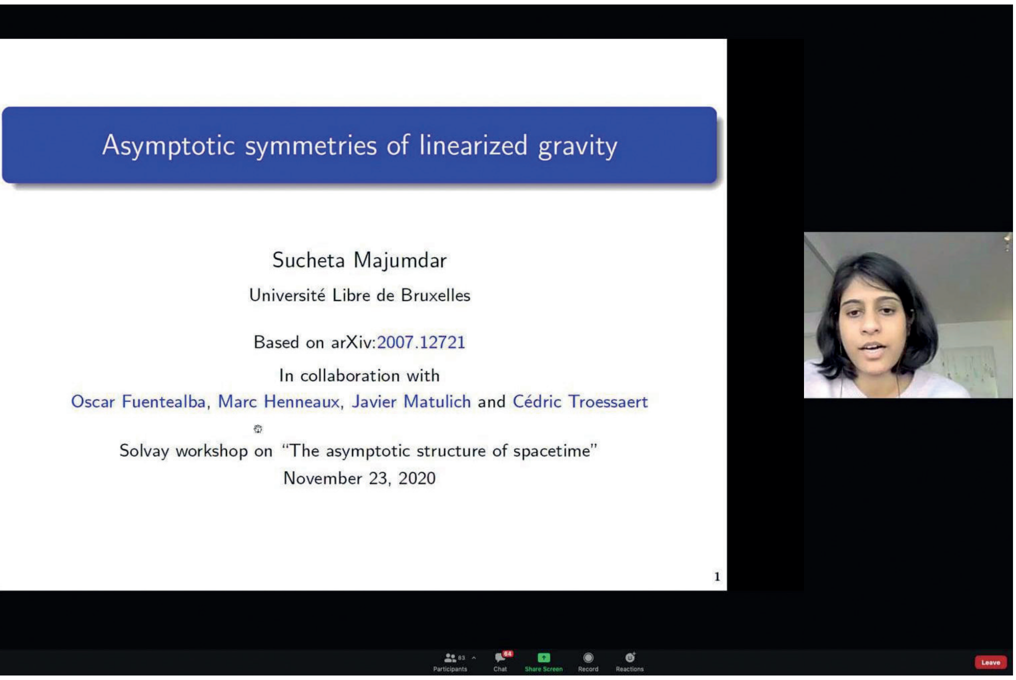
There has been a recent surge of interest in the exploration of the asymptotic structure of the gravitational field at infinity, with a special focus on the quantum implications of the emergence of these rich symmetry algebras.

The aim of the workshop was to take stock of the recent developments by bringing together active workers in the field. The scientific program reflected the wide spread of challenges raised by the investigation of the asymptotic structure of spacetime.

STRUCTURE OF SPACETIME ”

ORGANISING COMMITTEE

Glenn Barnich (ULB, Brussels, Belgium)
Geoffrey Compere (ULB, Brussels, Belgium)
Stéphane Detournay (ULB, Brussels, Belgium)
Marc Henneaux (ULB, Brussels, Belgium)



INVITED SPEAKERS

Ankit Aggarwal (ULB, Brussels, Belgium & UvA, The Netherlands)
Francesco Alessio (INFN, Napoli, Italy)
Martin Bonte (ULB, Brussels, Belgium)
Andrea Campoleoni (UMONS, Belgium)
Luca Ciambelli (ULB, Brussels, Belgium)
Laura Donnay (TUWien, Vienna, Austria)
Adrien Fiorucci (ULB, Brussels, Belgium)
Angelos Fotopoulos (Northeastern U., Boston, USA)
Oscar Fuentealba (ULB, Brussels, Belgium)
Marc Geiller (ENS, Lyon, France)
Daniel Grumiller (TUWien, Vienna, Austria)
Yannick Herfray (ULB, Brussels, Belgium)
Sucheta Majumdar (ULB, Brussels, Belgium)
Javier Matulich (ULB, Brussels, Belgium)
Turmoli Neogi (ULB, Brussels, Belgium)
Andrea Puhm (CPHT, Palaiseau, France)
Romain Ruzziconi (TUWien, Vienna, Austria)
Ali Seraj (ULB, Brussels, Belgium)
Roberto Tanzi (University of Bremen, Germany)
Cédric Troessaert (HERS, Libramont, Belgium)
Céline Zwikel (TUWien, Vienna, Austria)

PROGRAMME

Monday 23 November 2020

Welcome

Daniel Grumiller	*The asymptotic structure of lower-dimensional spacetimes*
Luca Ciambelli	*TMG with Compere-Song-Strominger boundary conditions*
Javier Matulich	*Asymptotic symmetries at spatial infinity*
Sucheta Majumdar	*Asymptotic symmetries of linearized gravity*
Adrien Fiorucci	*The Λ-BMS algebroid*
Marc Geiller	*Edge modes and corner symmetries*
Cédric Troessaert	*Boundary degrees of freedom and asymptotic symmetries*
Francesco Alessio	*Modular invariance in Casimir effect*
Martin Bonte	*Gravitons in a Casimir box*
Andrea Campoleoni	*Higher Spin Extensions of the BMS group*
Roberto Tanzi	*Asymptotic symmetries of YM at spatial infinity*

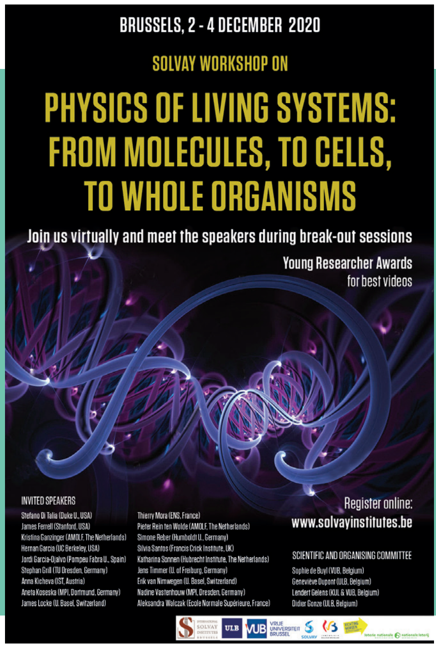
Tuesday 24 November 2020

Andrea Puhm	*Celestial CFT*
Céline Zwikel	*Charges in three-dimensional Bondi gauge*
Ali Seraj	*Flux-balance laws at null infinity*
Ankit Aggarwal	*Supertranslations in higher dimensions*
Romain Ruzziconi	*Coadjoint representation of the BMS group in four dimensions*
Laura Donnay	*Asymptotic symmetries and celestial CFT*
Angelos Fotopoulos	*Celestial CFT and extended super-BMS algebra*
Turmoli Neogi	*Asymptotic realization of the super-BMS algebra at spatial infinity*
Oscar Fuentealba	*Asymptotic structure of the Rarita-Schwinger theory in 4D at spatial infinity*
Yannick Herfray	*Super-geometry of null-infinity and Super-Twistors*

WORKSHOP ON

“PHYSICS OF FROM MOLECULES, TO WHOLE

2 - 4 DECEMBER 2020 – ONLINE



Living systems are dynamic and complex at all levels, ranging from the interaction of many molecules in the cell, to the coordinated behavior of many cells in multicellular organisms. Understanding this biological complexity requires an interdisciplinary approach. Therefore, this workshop brought together scientists with various backgrounds to tackle several fundamental questions in biology.

Molecules

The number of different molecules present in each cell is regulated by a large network that integrates metabolism, protein interactions and gene regulatory elements.

How do these multiple regulatory mechanisms work in concert and enable cells to make decisions? How do cells deal with the intrinsic stochasticity inherent to small DNA copy number and small numbers of molecules? Do specific regulatory network architectures optimize different physical quantities such as information transmission, energetic costs or dissipation?

Cells

It is known that the number of molecules also strongly depends on the location within the cell. The spatiotemporal organization of molecules in the cytoplasm and in various organelles plays a key role in coordinating cellular behavior, such as division, growth and locomotion. Perhaps one of the most intriguing open questions is how a cell senses and regulates its own size and shape, and how it controls the number and location of its various organelles. Molecular mechanisms and physical principles underlying cellular organization in general were explored.

Organisms

Whole organisms rely on the coordinated behavior of many cells to function. How is a developing embryo able to robustly create its body plan based on individual cell properties and cell- cell communication? Different strategies have been selected by different organisms, such as relying on morphogen gradients or using mosaic development to dictate spatial patterning of the embryo. General principles that lie at the heart of embryonic development were discussed.

LIVING SYSTEMS: TO CELLS, ORGANISMS ⸮⸮

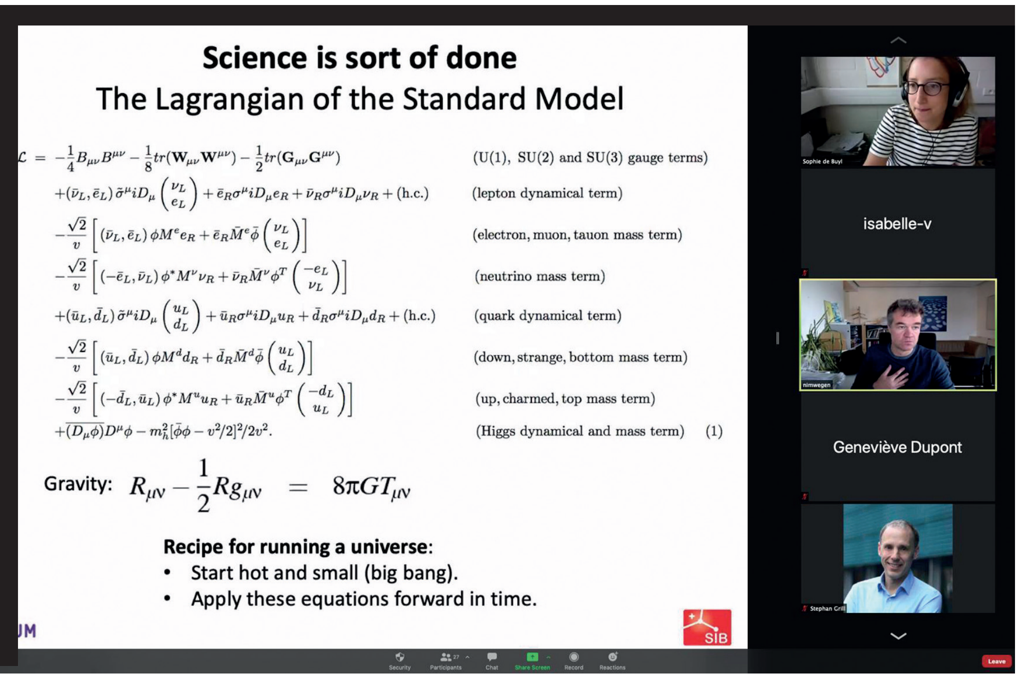
SCIENTIFIC AND ORGANISING COMMITTEE

Sophie de Buyl (VUB, Belgium)

Geneviève Dupont (ULB, Belgium)

Lendert Gelens (KUL & VUB, Belgium)

Didier Gonze (ULB, Belgium)



INVITED SPEAKERS

Stefano Di Talia (Duke U., USA)

James Ferrell (Stanford U., USA)

Kristina Ganzinger (AMOLF, The Netherlands)

Hernan Garcia (UC Berkeley, USA)

Jordi Garcia-Ojalvo (Pompeu Fabra U., Spain)

Stephan Grill (TU Dresden, Germany)

Anna Kicheva (IST, Austria)

Aneta Koseska (MPI, Dortmund, Germany)

James Locke (SLCU, U. of Cambridge, UK)

Thierry Mora (ENS, France)

Pieter Rein ten Wolde (AMOLF, The Netherlands)

Simone Reber (Humboldt U., Germany)

Silvia Santos (Francis Crick Institute, UK)

Katharina Sonnen (Hubrecht Institute, The Netherlands)

Jens Timmer (U. of Freiburg, Germany)

Erik van Nimwegen (U. Basel, Switzerland)

Nadine Vastenhouw (MPI, Dresden, Germany)

Aleksandra Walczak (ENS, France)

PROGRAMME

Wednesday 2 December 2020

Welcome address by Marc Henneaux

Session 1 chaired by Sophie de Buyl

Katharina Sonnen	*Signalling dynamics controlling mouse embryo development*
Silvia Santos	*Our first choices: decoding cellular signals during developmental transitions*
Anna Kicheva	*Coordination of patterning and growth in spinal cord development*

Break-out sessions: Meet the speakers + Break room

Session 2 chaired by Lendert Gelens

Simone Reber	*How complexity arises from molecular interactions*
Kristina Ganzinger	*Reconstituting signalling processes - Exploring information transfer in the immune system*
James Ferrell	*Self-organization of the cytoplasm*

Break-out sessions: Meet the speakers + Break room

Thursday 3 December 2020

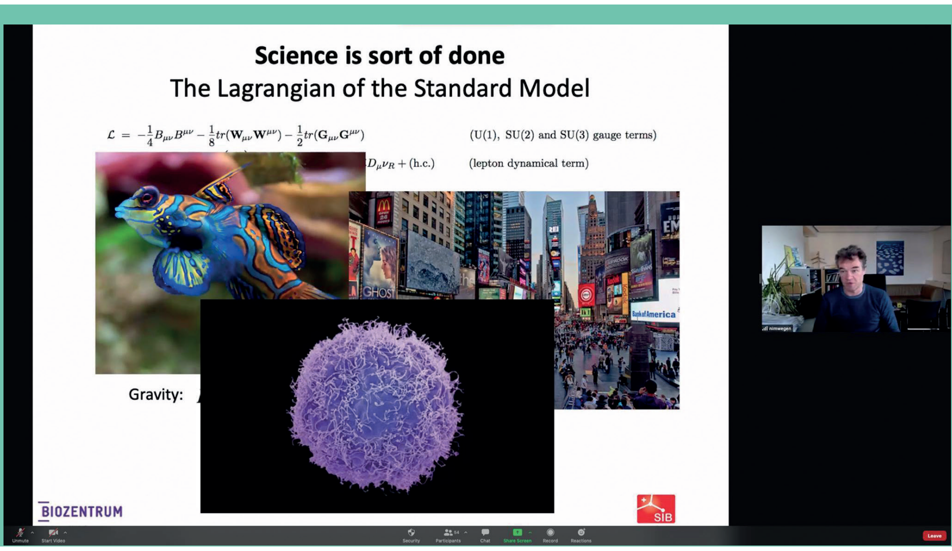
Session 3 chaired by Didier Gonze

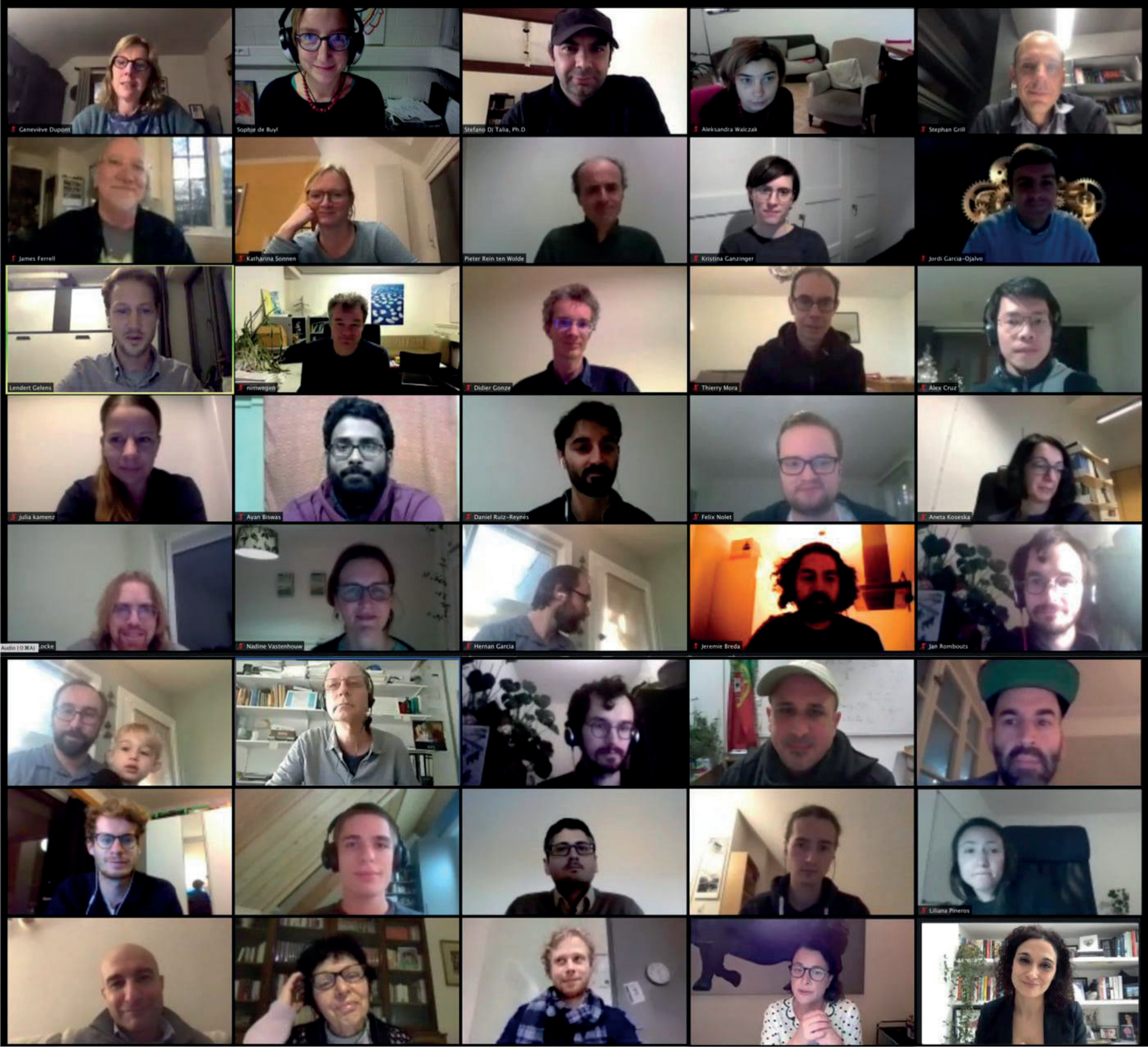
Thierry Mora	*Precision, adaptation and prediction in biological systems*
Jens Timmer	*A multi-scale model to improve anemia treatment in cancer patients*
Nadine Vastenhouw	*Transcription organizes euchromatin via microphase separation*

Break-out sessions: Meet the speakers + Break room

Session 4 chaired by Geneviève Dupont

Jordi Garcia-Ojalvo	*Robust cell-fate decision in the early embryo via intercellular mutual inhibition*
Stephan Grill	*Guided mechanochemical self-organization*
Stefano Di Talia	*Waves and flows in embryogenesis and regeneration*





Friday 4 December 2020

Session 5 chaired by Didier Gonze

Erik Van Nimwegen	*Stochastic gene regulation in bacteria*
Pieter Rein ten Wolde	*Optimal cellular sensing*
Aneta Koseska	*Principles of biochemical computations at criticality*

Break-out sessions: Meet the speakers + Break room

Session 6 chaired by Lendert Gelens

Aleksandra Walczak	*Decision making in early fly development*
James Locke	*Coordination of the plant circadian clock at the single cell level*
Hernan Garcia	*Dissecting transcriptional dynamics in development one burst at a time*

Young researcher award

MODAVE SUMMER

9 - 11 SEPTEMBER 2020

The Modave Summer School on Mathematical Physics is a yearly summer school in topics of theoretical physics ranging from quantum gravity and cosmology to theoretical particle physics and string theory. For this 2020 edition, the school exceptionally took place in Brussels as opposed to its traditional venue in Modave, a charming village in the Belgian Ardennes close to Huy. The Modave School is organised by PhD students for PhD students, and this makes it rather unique.

The courses are taught by Post-Docs or late PhD students, and they are all made of pedagogical, basic blackboard lectures about recent or fundamental topics in theoretical physics. Lectures of the sixteenth edition were centered around the following subjects: the geometry of gauge theories, topics in Lie algebras and quantum information.

This year marks the 16th 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.

ORGANISING COMMITTEE

Ankit Aggarwal (ULB)
Pieter Bomans (KUL)
Martin Bonte (ULB)
Jonathan Crabbé (ULB)
Marine De Clerck (VUB)
David De Filippi (UMONS)
Vasko Dimitrov (KUL)
Adrien Druart (ULB)
Ludovic Ducobu (UMONS)
Adrien Fiorucci (ULB)
Kwinten Fransen (KUL)
Yegor Goncharov (UMONS/U. de Tours)
Philip Hacker (VUB)
Lorenzo Küchler (ULB/KUL)
Yan Liu (ULB)
Vincent Min (KUL)
Daniel Naegels (ULB)
Pierluigi Niro (ULB/VUB)
Antoine Pasternak (ULB)
Simon Pekar (UMONS)
Romain Ruzziconi (ULB)
Colin Sterckx (ULB)
Rob Tielemans (KUL)
Magnus Tournoy (KUL)
Lucas Traina (UMONS)
Guillaume Valette (ULB)
Vincent Van Hemelryck (KUL)
Jesse van Muiden (KUL)
Quentin Vandermiers (ULB)
Gerben Venken (KUL)
Sofia Zhidkova (VUB)

SCHOOL IN MATHEMATICAL PHYSICS

PARTICIPANTS

Alessio Francesco (ULB)
Chatwin-Davies Aidan (KUL)
De Clerck Marine (VUB)
De Filippi David (UMONS)
Delfante Arnaud (UMONS)
Demulder Saskia (MPI Munich)
Ducobu Ludovic (UMONS)
François Jordan (UMONS)
Fransen Kwinten (KUL)
Hacker Philip (VUB)
Knysh Maria (VUB)
Lekeu Victor (Imperial College London)
Naegels Daniel (ULB)
Niro Pierluigi (ULB/VUB)
Pasternak Antoine (ULB)
Sterckx Colin (ULB)
Van Hemelryck Vincent (KUL)
Vandermiers Quentin (ULB)
Vekemans Annelien (KUL)
Zwikel Céline (TU Wien)

LECTURES

USEFUL TOPICS IN LIE ALGEBRAS

by Victor Lekeu (Imperial College, London)

In these lectures, I will explain a variety of topics in the theory of Lie algebras: real forms of (complex, finite-dimensional) simple Lie algebras, Chevalley-Eilenberg cohomology, central extensions, Kac-Moody and loop algebras. They appear in many areas of theoretical physics and I therefore hope that the title is not a complete lie. Plenty of exercises will be provided; familiarity with roots and Dynkin diagrams is useful but not absolutely necessary.

DIFFERENTIAL GEOMETRY OF GAUGE THEORY

by Jordan François (UMONS)

We propose an introduction to the differential geometry of connections on fiber bundles underlying the physics of (classical) gauge theories. Our first aim is to show how Ehresmann connections are behind Yang-Mills/Utiyama theory. We will then be prepared to appreciate why Cartan connections provide a compelling geometric framework for gauge theories of gravity (the tetrad formulation of GR being the most relevant special case). An important takeaway will be the recipe for cooking a gauge theory.

If time allows it, we will end by a presentation of the “dressing field method” which can be seen either as a way to achieve gauge symmetry reduction, or as a diagnosis tool to detect fictitious gauge symmetries in a theory.

QUANTUM INFORMATION

by Aidan Chatwin-Davies (KUL, Leuven)

Quantum information science sits at an intersection point of physics, mathematics, and computer science. The field concerns itself with the information contained in quantum mechanical systems, how that information can be encoded, manipulated, and retrieved, and how these operations' properties, capabilities, and limitations can be quantified. As we sit at the cusp of the era of quantum computers, the practical importance of quantum information science only continues to increase. In parallel, quantum information science continues to drive new discoveries and further our theoretical understanding of questions in high energy physics.

The aim of these lectures is to introduce a handful of core ideas from quantum information science that figure prominently in modern research on quantum gravity. The central concept that will form the base of our studies is that of a quantum channel; that is, the most general map between quantum states and between operators on Hilbert space. A large part of the lectures will be honest-to-goodness quantum information theory, and we will try to avoid cutting too many corners in a rush to get to gravity. Nevertheless, we will still manage to see how a few problems in high energy physics, such as the black hole information problem or bulk reconstruction in AdS/CFT, can be cast in the information theoretic language that we will have set up.

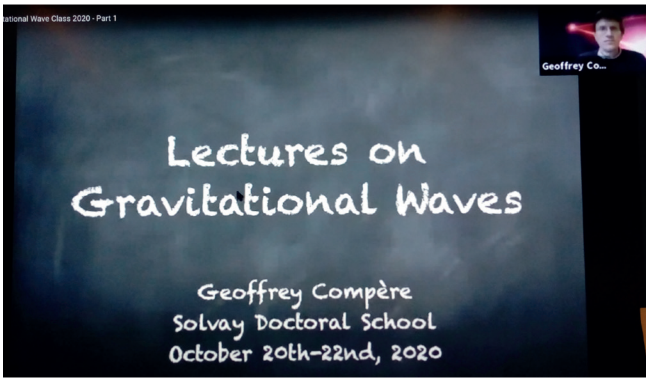
DOCTORAL

"QUANTUM FIELD THEORY, STRINGS AND GRAVITY"

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

PROGRAMME



Brussels | 5 - 23 October - ONLINE

Adel Bilal	*Advanced Quantum Field Theory*
Alberto Lerda	*String Theory I*
Marco Billò	*String Theory II*
Monica Guica	*Advanced GR*
Geoffrey Compère	*Gravitational waves*

Geneva | 2 - 20 November - ONLINE

Silvia Penati	*Introduction to Supersymmetry*
Domenico Orlando	*Introduction to Superstrings*
Susanne Reffert	*D-branes and Superstring Dualities*
Julian Sonner	*AdS/CFT*
Antoine van Proeyen	*Introduction to Supergravity*

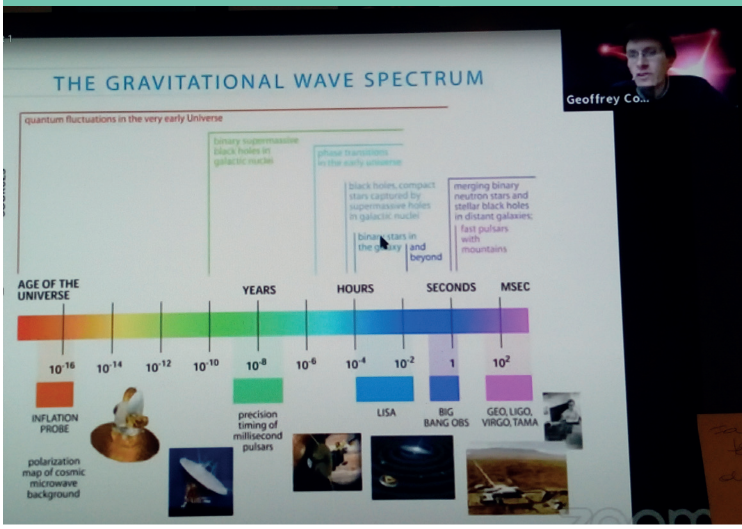
Amsterdam | 30 November - 18 December - ONLINE

Agnese Bissi	*Modern methods in QFT*
Kyriakos Papadodimas	*AdS/CFT*
Erik Verlinde	*Quantum Gravity and Quantum Information*
Michael Walter	*Quantum Information and Quantum Gravity*
Marcel Vonk	*Resurgence*

SCHOOL

PARTICIPATING INSTITUTIONS

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



PARTICIPANTS

Aguilar Gutierrez Sergio Ernesto (KU Leuven, Belgium)

Arenas-Henriquez Gabriel (Durham University, UK)

Bhattacharyya Archishna (University of Amsterdam, The Netherlands)

Bielli Daniele (Milano-Bicocca, Italy and University of Surrey, UK)

Bintanja Suzanne (University of Amsterdam, The Netherlands)

Bu Wei (University of Edinburgh, UK)

Di Ubaldo Gabriele (École Normale Supérieure, Paris, France)

Diaz Felipe (Universidad Andres Bello, Chile)

Georgescu Silvia (École polytechnique, Paris, France)

Häring Kelian (École polytechnique fédérale de Lausanne)

Katona David (University of Edinburgh, UK)

Knysh Maria (VUB, Belgium)

Liska Diego (University of Amsterdam, The Netherlands)

Machet Ludovico (KU Leuven/ULB, Belgium)

Marconnet Paul (Lyon 1 University, France)

Matijn François (either Ghent University or The University of Queensland)

Monnee Jeroen (Utrecht University, The Netherlands)

Moser Rafael

Musaeus Jørgen (University of Edinburgh, UK)

Oh Tae Hwan (Kyung Hee University, Republic of Korea)

Pano Yorgo (École Polytechnique, Palaiseau, France)

Parra De Freitas Hector Alejandro (Institut de Physique Theorique CEA/Saclay, France)

Passaro Davide (University of Amsterdam, The Netherlands)

Pavlov Maxim (VUB, Belgium)

Pelliconi Pietro (Italy)

Pellizzani Vito (University of Bern, Switzerland)

Rella Claudia (University of Geneva, Switzerland)

Rivera David (École Polytechnique, France)

Somerhausen Antoine (ULB, Belgium)

Sottovia Filippo (École Polytechnique Paris, France)

Toulikas Dimitrios (IPhT CEA Saclay, France)

van Spaendonck Alexander (University of Amsterdam, The Netherlands)

Vandepopeliere Romain (ULB, Belgium)

Vekemans Annelien (KU Leuven, Belgium)

Vitouladitis Stathis (University of Amsterdam, The Netherlands)

Zhang Xuao (KU Leuven, Belgium)

STUDENT'S OPINION

Ludovico Machet I KU Leuven & ULB

PhD student

My PhD career in the theoretical and mathematical physics group at ULB started with the Solvay Doctoral School. This program, treating a large span of subjects, was a great opportunity to be exposed to the current frontiers in theoretical physics. It was a precious chance to go through fields that I did not cover during my master's studies or which are not among my direct research interests. Ranging from gravitational waves to advanced string theory, the school's three blocks of lectures have been an effective and intense way to give students the basis they needed to orient themselves in the research arena.

The 2020 School has been different in many ways with respect to previous editions. First of all, the entire program was held online. This yielded challenges for both the lecturers, adapting the teaching and the exercises session format, and the students, for finding the right amount of motivation to wake up in the morning and follow the classes on Zoom. Also, the virtual setting somewhat limited the social interactions and the discussions with the other students, without the chance to physically meet and enjoy the stimulating environment of the host universities. Still, it was fruitful to meet first-year PhD students from all over Europe and to exchange about each other experiences and interests.

Thus, the Solvay School was for me a perfectly fitted program to get started with my PhD. The organizers and lecturers' work to put together the school in such constrained times has to be acknowledged!

Ludovico Machet

STUDENT'S OPINION

Antoine Somerhausen I ULB

PhD student

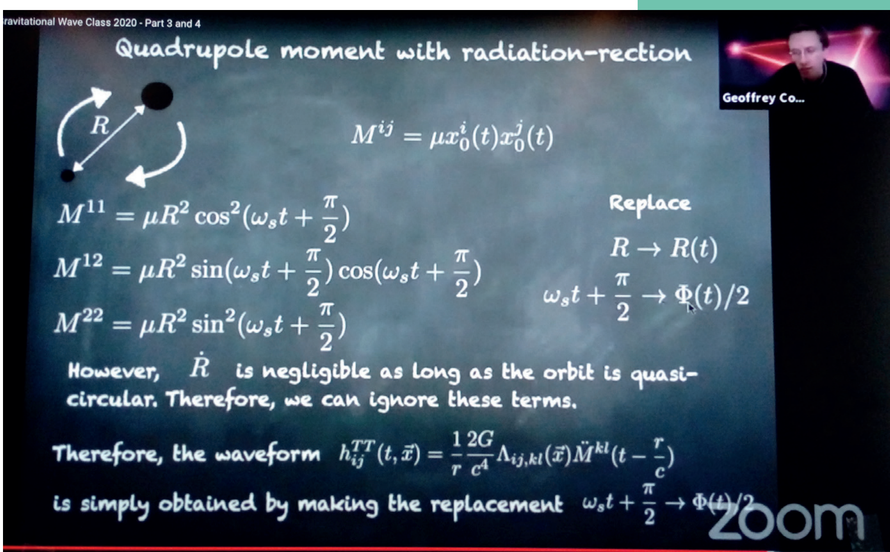
As a fresh PhD student part of the mathematical physics group at ULB, I attended the Solvay doctoral school. Obviously, this year has been very special due to the global pandemic. As a result, the measures that were taken- for instance online courses- have quite changed the very organization of the school.

Interestingly, even if the social experience was quite different, I was very impressed by the learning experience we were allowed to enjoy. Lecturers were actually very well prepared and we found great ways to have social interactions.

I enjoyed very much the lectures: the content was stimulating, and provided me with strong theoretical foundations for the pursuit of my research. Overall, I can really feel that I acquired cutting-edge knowledge in topics such as string theory, advanced gravitation and quantum field theory in a very dynamic and pleasant atmosphere.

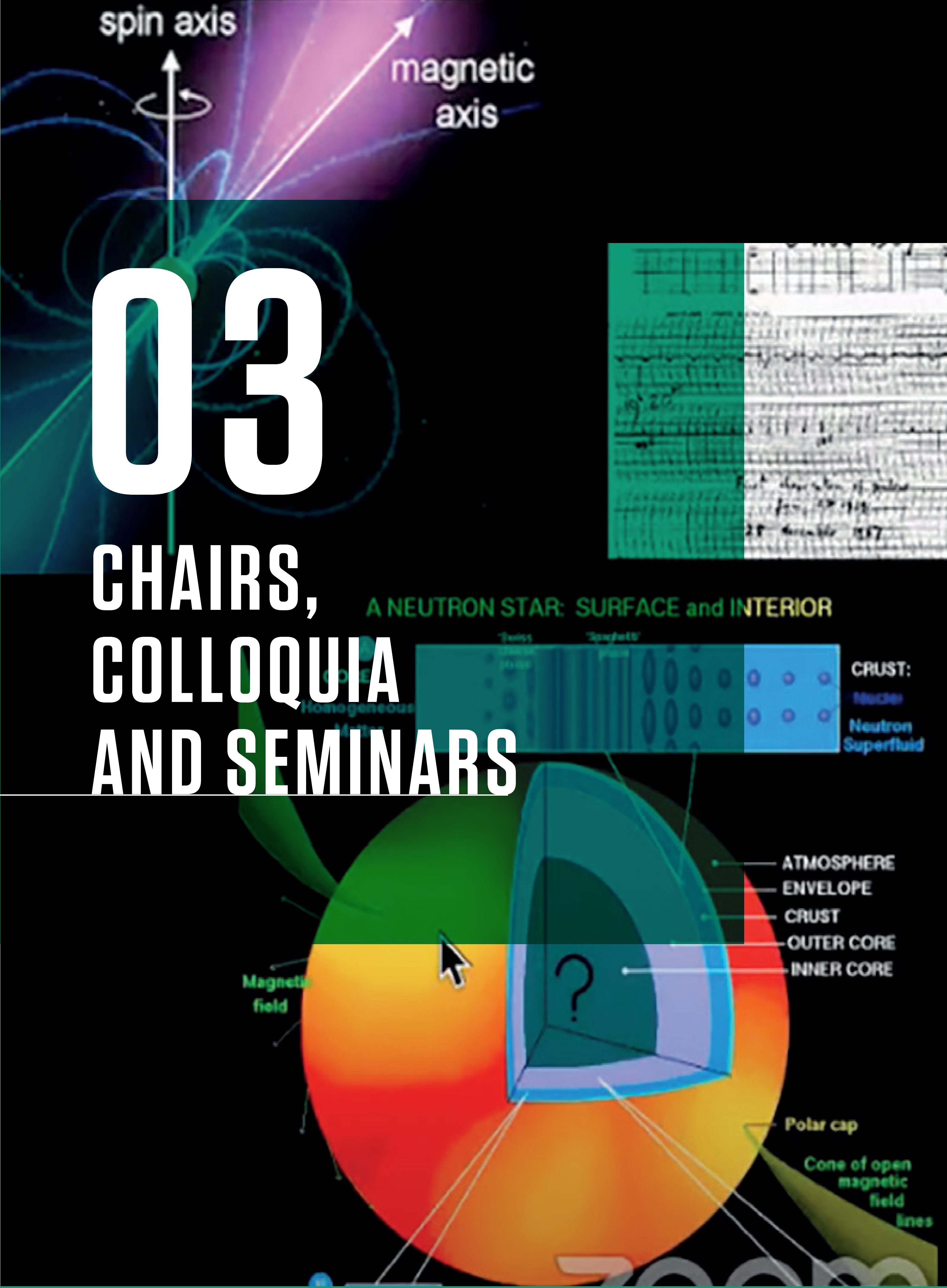
Undoubtedly, in the end, the doctoral school was a success!

Antoine Somerhausen



03

CHAIRS, COLLOQUIA AND SEMINARS



INTERNATIONAL

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.

The Solvay Professors for 2020 were Professors Joanna Aizenberg (Harvard) for chemistry and Roger Blandford (Stanford) for physics. Because of the sanitary crisis, however, the 2020 chair activities have been postponed to 2021. We thank the 2020 chair holders for their cooperative understanding in rescheduling the programme. The 2020 chair activities will be detailed in our 2021 report.

We will review here instead fruitful developments initiated by the 2019 Solvay chair in chemistry. A new research project between Professor Frenking (2019 chair holder) and its host chemistry group at the VUB started during his stay in Belgium and resulted in new discoveries, which led to a highly visible joint publication in a leading chemistry journal.

2019 INTERNATIONAL SOLVAY CHAIR IN CHEMISTRY

The 2019 International Solvay Chair in Chemistry was awarded to Professor Gernot Frenking, Professor Emeritus at the Philipps-Universität Marburg.

During his 2019 Solvay Chair Professor Frenking spent two months in Brussels (March and November) where he was hosted in the ALGC group of the VUB (Prof. Frank De Proft and Prof. Em. Paul Geerlings). In his masterly inaugural lecture on March 12 he treated the historic development of the chemical bond and the physical understanding of chemical bonding with marvelous insight, great enthusiasm and in a way accessible to the broad audience present at this occasion.

In the four following lectures (two in March and two in November) more specialized, state-of-the-art issues were addressed which convinced the audience that even today "tales from the unexpected" can be told on a "classical" subject as the chemical bond.

Precisely the seminar on one of these themes, the recently discovered smoothening of the barrier between main group and transition metal group elements, was the starting point of a collaboration between Prof. Frenking and the ALGC group during his stay. The border between main group elements and transition metals, a paradigm connected

SOLVAY CHAIRS

with the structure of Mendeleev's Periodic Table, was recently and repeatedly challenged among others by the observation that octa-coordinated complexes between alkaline earth elements with N_2 and CO were stable and their bonding could be explained with state-of-the-art quantum chemical electronic structure methods. Whereas Prof. Frenking's interest had mainly been oriented towards structural aspects, discussions with him during research seminars at ALGC led to the idea to explore also reactivity aspects, more precisely in the context of Conceptual Density Functional Theory, one of the main research lines of the ALGC group. A project was set up in March 2019 and thanks to the precious help of Drs. Tom Bettens at the VUB and Prof. Sudip Pan in Germany, a substantial amount of theoretical and computational work was done in the summer, so that in November 2019, during the second month of Prof. Frenking's stay, data could be refined, first conclusions could be put forward and a blueprint for a publication could be prepared.

The main result from the investigation is as follows. Concentrating on the N_2 ligands of octahedral complexes with Ca, Sr, Ba it turned out that these main group metals activate the strong, non-polar bond in N_2, similarly, and even more strongly than their transition metal congeners in groups IV (Ti, Zr, Hf) and Group VI (Cr, Mo, W).
The consequence is that within a given row of the Periodic Table the alkaline earth metals are proper candidates in the quest for optimizing the N_2 fixation process and thereby, by replacing transition metals, cope with problems of relative abundance and cost.

The paper was very well received in "Chemistry - a European Journal", was selected as a "Hot" paper, and cover feature of the Edition of October 6, 2020. Its success highlights the possibilities for Belgian research groups for extending their scientific networks, through the Solvay Chairs.

Reference:
T. Bettens, S. Pan, F. De Proft, G. Frenking, P. Geerlings, "Alkaline Earth Metal Activate N_2 and CO in Cubic Complexes just Like Transition Metals. A Conceptual Density Functional Theory and Energy Decomposition Analysis".
Chem.Eur.J., 26,12785-12793 (2020)

Professor Frenking is a quantum-chemist with a long standing and world-wide reputation.

At young age he already worked with Nobel-laureate Kenichi Fukui in Kyoto and after his PhD (1979) and Habilitation (1984) from the Technical University of Berlin he went to the US working with Henry Schaeffer III

at the University of California and he joined the Stanford Research Institute as Staff Scientist in 1985. In 1990 he returned to Germany as Professor at the University of Marburg. After his retirement in 2014 he continued his research in Germany as Professor Emeritus but also served as Ikerbasque Visiting Research Professor at the Donostia International Physics Center and the Nanjing Tech University in China.

His research has always been fundamental in nature and concerned all aspects of the chemical bond, one of the basic pillars in molecular chemistry: dative bonding in main group molecules, bonding analysis of molecules and reaction mechanisms in small molecule activation… Professor Frenking has been extremely productive being the author or co-author of around 800 papers in International Journals. Among the many honors and awards he received we mention the 2009 Schrödinger medal from the World Association of Theoretical and Computational Chemists (WATOC).

COLLOQUIA

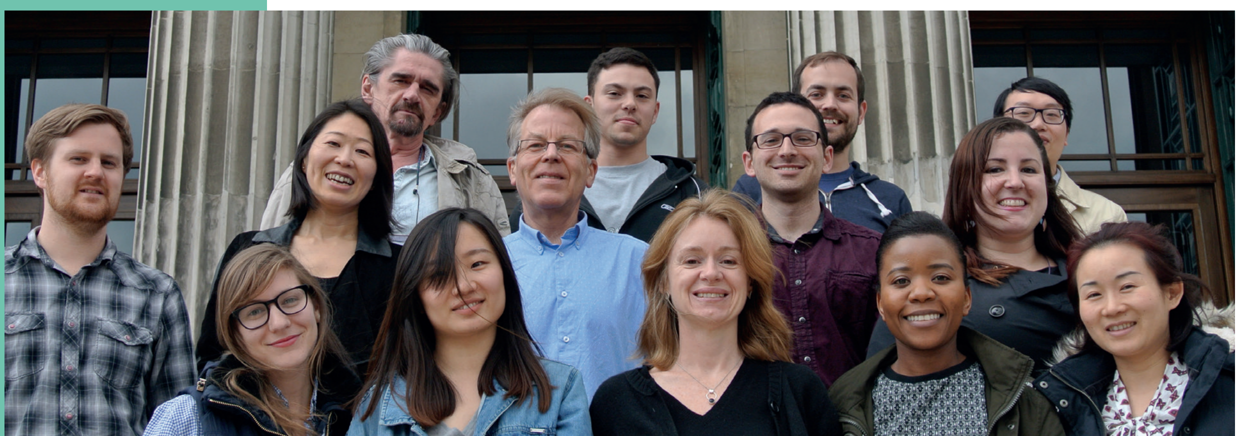
BESPOKE CRYSTALS: BIO-INSPIRED CONTROL OVER THE STRUCTURE AND PROPERTIES OF CRYSTALS

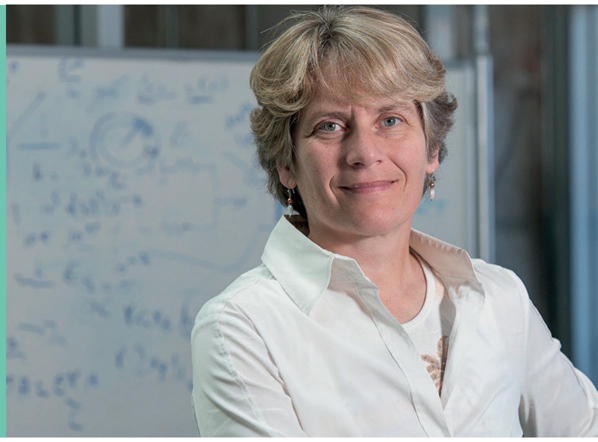
Professor Fiona Meldrum
University of Leeds, UK

21 FEBRUARY 2020

Crystallisation underpins a vast range of processes including the production of nanomaterials and pharmaceuticals, the formation of bones and seashells, environmental issues such as weathering, and unwanted crystallisation such as scale deposition. This talk will describe strategies for controlling crystal nucleation and growth, where particular inspiration is taken from biomineralisation processes. Crystals with complex morphologies can be generated using simple templating approaches, while microfluidic systems provide opportunities to interact with growing crystals and gain superior control. The biogenic demonstration that even single crystal biominerals are composites in which organic macromolecules are associated with the inorganic phase is then used as an inspiration to generate single crystal nanocomposites.

Finally, I will address the most challenging topic of all — control over nucleation — and show that surface topography can be highly effective in promoting nucleation.





THERAPEUTIC OPPORTUNITIES IN GLYCOSCIENCE

Professor Carolyn Bertozzi
Stanford University, USA

11 MARCH 2020

Cell surface glycans constitute a rich biomolecular dataset that drives both normal and pathological processes. Their "readers" are glycan-binding receptors that can engage in cell-cell interactions and cell signaling. Our research focuses on mechanistic studies of glycan/receptor biology and applications of this knowledge to new therapeutic strategies. Our recent efforts center on pathogenic glycans in the tumor microenvironment and new therapeutic modalities based on the concept of targeted degradation.

The colloquium of Professor Bertozzi was organized in the context of her visit to Belgium to receive the Chemistry for the Future Solvay Prize awarded by the Solvay Company.

THE CHEMISTRY FOR THE FUTURE SOLVAY PRIZE RECOGNIZES MAJOR SCIENTIFIC DISCOVERIES

The 2020 Chemistry for the Future Solvay Prize was awarded to Carolyn Bertozzi, Professor of Chemistry at Stanford University (USA), for her invention of bioorthogonal chemical reactions that can be performed in living cells and organisms.
These reactions can be used to label specific molecules in cells for imaging, for drug target identification and the creation of next-generation biotherapeutics – ultimately helping to diagnose and treat diseases in the long term, particularly in cancer and infectious diseases.

The Chemistry for the Future Solvay Prize recognizes major scientific discoveries with the potential to shape tomorrow's chemistry and help human progress. Created in 2013, the Chemistry for the Future Solvay Prize perpetuates Ernest Solvay's, lifelong support of and passion for scientific research. The objective is to endorse basic research and highlight the essential role of chemistry, both as a science and an industry, in helping solve some of the world's most pressing issues.

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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.
Most of these seminars took place online.

JANUARY

Gravitational waves: theory and observations (series of 4 lectures)
Chris Van Den Broeck (University of Utrecht, the Netherlands)

FEBRUARY

Electromagnetic soft charges in Anti-de Sitter space
Erfan Esmaeili

Relations between transport and chaos in holographic theories
Richard Davison

Interactions of metric-like higher-spin fields
Stefan Fredenhagen

MARCH

Signatures of chaos and the structure of eigenstates in holographic theories
Julian Sonner

A Kaluza-Klein spectrometer from exceptional field theory
Emanuel Malek

Three-dimensional quantum gravity, Ponzano-Regge model and Holography
Christophe Goeller

Central charges of 2d superconformal defects
Brandon Robinson

Twisting with a flip
Guido Festuccia

Near null hypersurface symmetries and T-Witt algebra
Céline Zwikel

SEPTEMBER

Higher-derivative Supergravity and AdS4 Holography
Valentin Reys

OCTOBER

Compactification, duality and black-hole entropy in stringy black holes
Tomas Ortin

Mukund Rangamani

Strong Cosmic Censorship (one of the legacies of Roger Penrose)
Oscar Dias

APRIL

Cosmological Decoherence from Thermal Gravitons

Aidan Chatwin-Davies

String theory on AdS3 in its tensionless limit

Gaston Giribet

TTbar deformation and long-range spin chains

Yunfeng Jiang

KKLT and the Swampland Conjectures

Ralph Blumenagen

MAY

Holographic probes of inner horizons

Gábor Sárosi

Virasoro hair for axisymmetric Killing horizons

Antony Speranza

Nothing is certain in string compactifications

Irene Valenzuela and Miguel Montero

Page curves in asymptotically flat spacetime

Lárus Thorlacius

JUNE

Comments on the Lagrangian formulation of gravity as a double copy

Dario Francia

NOVEMBER

Carlo Heissenberg

The holography of NUT charge

Rob Leigh

DECEMBER

Twisting the abelian (2,0) multiplet: constraints, BV, and pure spinors

Ingmar Saberi

Gravitational turbulence in Large D

Christiana Pantelidou

04

RESEARCH

RESEARCH ON STRING THEORY

GROUPS OF PROFESSORS MARC HENNEAUX | ULB

RESEARCHERS

Faculty Members

Riccardo Argurio (ULB)
Vijay Balasubramanian (VUB)
Glenn Barnich (ULB)
Vladimir Belinski (ICRAN, Italy)
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, Germany)
Laura Lopez Honorez (VUB)
Alberto Mariotti (VUB)
Mairi Sakellariadou (VUB)
Alexander Sevrin (VUB)
Dan Thompson (VUB)

Postdoctoral Researchers

Francesco Alessio (ULB & Naples)
Alexandros Spyridon Arvanitakis (VUB)
Ahmed Aqeek (VUB)
Simone Blasi (VUB)
Luca Ciambelli (ULB)
Oscar Fuentealba (ULB)
Eduardo García-Valdecasas (ULB)
Surbhi Khetrapal (VUB)
Mikhael Khramtsov (VUB)
Raimon Luna (ULB)
Sucheta Majumdar (ULB)
Javier Matulich (ULB)
Wout Merbis (ULB)
Saereh Najjari (VUB)
Turmoli Neogi (ULB)
Romain Pascalie (ULB)
Stefan Prohazka (ULB)
Charles Rabideau (VUB)
Patricio Salgado-Rebolledo (ULB)
Ali Seraj (ULB)
Charlotte Sleight (ULB)
Hongbao Zhang (VUB)

Doctoral Researchers

Ankit Aggarwal (ULB)
Martin Bonte (ULB)
Marine De Clerck (VUB)
Adrien Druart (ULB)
Adrien Fiorucci (ULB)
Philip Hacker (VUB)
Sam Junius (VUB)
Maria Knysh (VUB)
Lorenzo Küchler (ULB)
Yan Liu (ULB)
Ludovico Machet (ULB)
Daniel Naegels (ULB)
Pierluigi Niro (ULB/VUB)
Antoine Pasternak (ULB)
Maxim Pavlov (VUB)
Romain Ruzziconi (ULB)
Antoine Somerhausen (ULB)
Colin Sterckx (ULB)
Kevin Turbang (VUB)
Romain Vandepopeliere (ULB)
Quentin Vandermiers (ULB)
Sofia Zhidkova (VUB)

GRAVITATION, AND COSMOLOGY

AND ALEXANDER SEVRIN | 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 115 published papers and preprints submitted for publication. These are listed on pages 87 - 92. 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

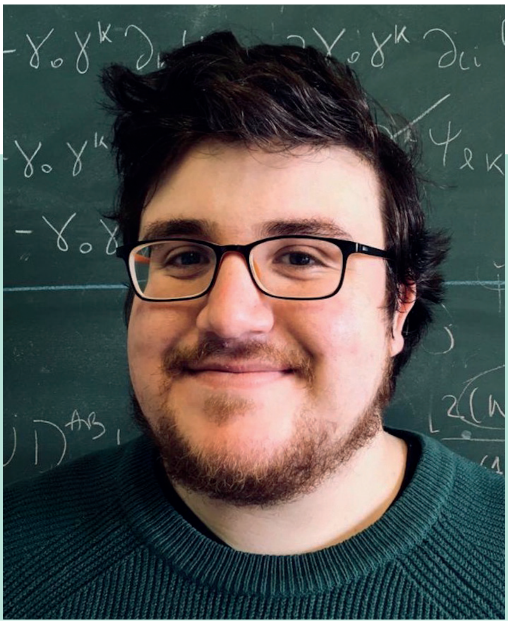
Thanks to a special gift of Mrs. Marina Solvay, the "Marina Solvay Fellowship" was created in 2012.
The fellowship enables a brilliant young researcher to pursue her or his career as a postdoctoral fellow in the group of "physique théorique et mathématique" of the ULB.

List of Marina Solvay fellows

Waldemar Schulgin (2012-2014)
David Tempo (2015)
Jelle Hartong (2016)
Adolfo Guarino (2017)
Charlotte Sleight (2018)
Sucheta Majumdar (2019)

2020 MARINA SOLVAY FELLOW

Oscar Fuentealba | Postdoctoral researcher | ULB

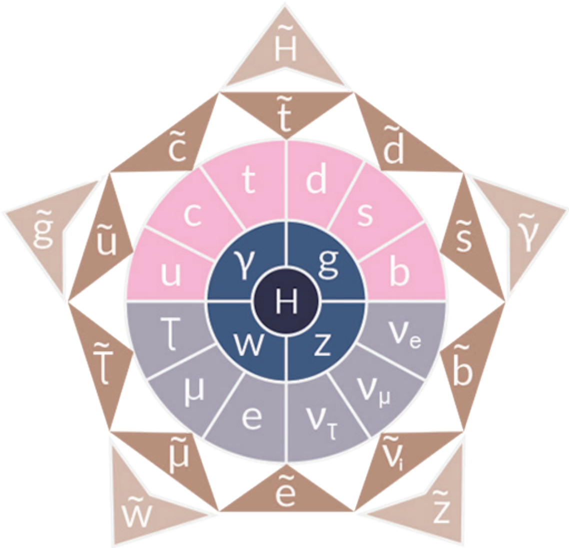


Oscar Fuentealba got his PhD degree at the University of Concepción (Chile) in 2015 before joining the group of the Director at ULB. His research deals with Einstein theory of gravity: black hole solutions, black hole thermodynamics, supersymmetric models. More recently, he worked on asymptotic symmetries of gravity in the asymptotically flat space context, where infinite dimensional groups appear at infinity. He held the Marina Solvay fellowship in 2020.

Symmetries: a powerful tool for the understanding of nature

Without any doubt, symmetries have played a central role in a wide gamut of disciplines, from arts to mathematics. In the context of theoretical physics, the understanding of symmetries has yielded powerful mathematical tools, which have spanned a number of impressive advances towards one of the most difficult problems, namely the elusive quantum description of the gravitational field.

Among the most notable developments, we can find to the supersymmetric field theories. Supersymmetry defines a symmetry between the carriers of the interactions (bosons) and matter (fermions). One of its renowned realizations corresponds to the theory of maximal supergravity, which has shown to cancel many of the expected ultraviolet divergences present in a gravitational theory.



Representation of the standard model of elementary particles, one the most important breakthrough in the search for a unified theory of fundamental interactions. The blue circle contains to the bosons, while in the exterior circle we see leptons and quarks (fermions). The remaining objects correspond to hypothetical particles proposed by supersymmetry, whose existence is still to be tested by the big experiments at the Large Hadron Collider at CERN.

Other very exciting topic that has attracted a great deal of attention in the last decades is the so-called AdS/CFT correspondence. The latter conjectures that a theory of quantum gravity with negative cosmological constant should be equivalent to a conformal field theory defined in the boundary of the spacetime. Nonetheless, an explicit realization along these lines was found even earlier, in the work by Brown and Henneaux, who showed the emergence of the conformal algebra in two dimensions, an infinite-dimensional symmetry algebra, in the canonical prescription of the asymptotic symmetries of AdS spacetimes in three dimensions. As a moral, we have learned that a deepen understanding of a gravitational theory is subordinated to a rigorous study of its asymptotic structure.

Disentangling and extending the (super-)BMS symmetry at infinity

General Relativity has a very rich asymptotic structure. In fact, similarly to the case of its three-dimensional “relative”, it is also endowed with an infinite amount of symmetries, to wit the so-called BMS group, found by Bondi, van der Burg, Metzner and Sachs in the 60’s. Specifically, the BMS symmetry turns out to be an enhancement of the Poincaré symmetry with a generalization of angle-dependent translations, dubbed as supertranslations. These have shown to possess fascinating connections with very diverse topics as for instance soft theorems, the memory effect and the information loss paradox in black holes. However, there are still many questions that require a deeper understanding of the BMS group. For example, in spite of these symmetries were first discovered at the null infinity (region of the spacetime that is only reached by radiation), it was only recently that they were rediscovered at spatial infinity. This task was achieved by using a set of boundary conditions satisfying a new type of parity conditions.
The emergence of the BMS symmetry at spatial infinity allowed to apply all the machinery available to derive well-defined canonical generators for the supertranslation charges.

Taking advantage of these developments, we have performed the study of the structure of the BMS symmetry, showing how Poincaré transformations and improper gauge symmetries (BMS supertranslations) of the free Pauli-Fierz theory merge into the full BMS group as one switches on the gravitational coupling [1]. Another interesting line of research that we are addressing concerns the existence of infinite-dimensional fermionic representations of the Lorentz group and possible extensions of the super-BMS group as the canonical realization of the asymptotic symmetries of supergravity in four spacetime dimensions at spatial infinity. For this, we started the analysis in the case of free spin-3/2 field, also known as the Rarita-Schwinger theory, where we were able to formulate consistent boundary conditions that led to a twofold of angle-dependent fermionic charges [2]. We are currently working in the full interacting case, where it is expected to find an infinite-dimensional set of fermionic charges, which would stand for the "square roots" of the BMS supertranslations.

The search for infinite-dimensional extensions of the conformal group

Extensions of the Poincaré group are expected to play a relevant role in physics. One example is the aforementioned BMS group, which naturally emerges in the case of asymptotically flat spacetimes. Other example is the case of relativistic systems with scale invariance, where the symmetries are enhanced to the conformal group. It is then natural to wonder on the possible compatibility of the BMS group with the conformal group. This is the question we recently addressed with Professors Hernán A. González, Alfredo Pérez, David Tempo and Ricardo Troncoso in [3]. Specifically, we found a novel (super)conformal extension of the BMS algebra in three dimensions, where apart from the infinite-number of "superdilations", we managed to incorporate an infinite-number of "superspecial conformal transformations". We also showed that an explicit canonical realization of these symmetries emerges from the asymptotic structure of conformal gravity in three dimensions endowed with a new set of boundary conditions. The found symmetry algebra turns out to be nonlinear, a feature that is also present in higher spin extensions of infinite-dimensional algebras, known as W-algebras. It is also worth mentioning this algebra can be understood as an infinite-dimensional nonlinear extension of the AdS algebra in four dimensions with nontrivial central charges, suggesting the possibility of a different version of the AdS4/CFT3 correspondence with enhanced symmetries.

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RESEARCH INTERESTS AND ACHIEVEMENTS OF SOME OTHER MEMBERS

Glenn Barnich | Professor | ULB

TEAM

Researchers from the Theoretical and Mathematical Physics group at ULB currently working on this topic are Francesco Alessio, Glenn Barnich, Martin Bonte, and Luca Ciambelli. Other group members that have expressed an interest in the topic and that will hopefully join in the effort are Ankit Aggarwal, Stephane Detournay, Sucheta Majumdar, and Ali Seraj.

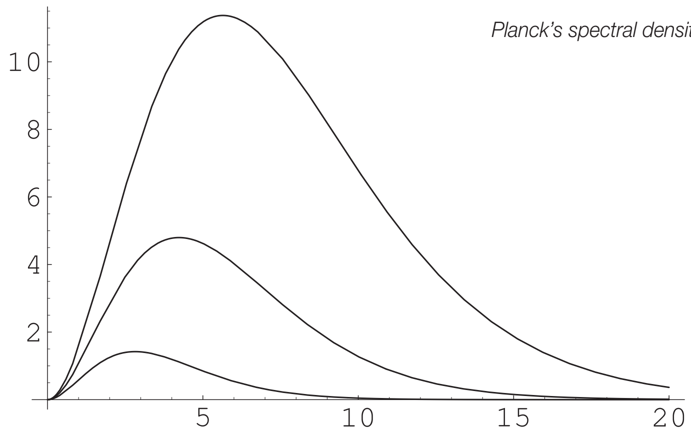
Potential external collaborators include Axel Kleinschmidt (AEI Golm), Malte Henkel (Université de Lorraine), James Quach (University of Adelaide), and Shahin Sheikh-Jabbari (IPM Tehran).

From black hole entropy to Casimir physics, and back

1 Black hole entropy

Black holes are exact solutions of general relativity with direct astrophysical relevance. These solutions are characterized by thermodynamic properties, including an entropy that scales like the area rather than the volume. Understanding the microscopic origin of this unusual behavior is generally believed to be an important piece of the theoretical puzzle posed by a quantum theory of gravity.

Why then does one expect the entropy to scale like the volume? In the case of the electromagnetic field for instance, suppose one wants to describe black body radiation, that is to say, electromagnetic radiation in equilibrium with its environment. The standard textbook approach consists in putting the free electromagnetic field in a rectangular box by imposing periodic boundary conditions. In Fourier space, the system appears as a collection of non-interacting harmonic oscillators with discretized angular frequencies so that the logarithm of the partition function turns into the sum of the logarithms of these individual oscillators. Since such discrete sums are rather difficult to perform, one considers the limit of a large box where the sums may be replaced by integrals, at the prize of an overall factor proportional to the volume. In the large volume limit, the result does not depend on the choice of boundary conditions. This may be checked by repeating the computation with Dirichlet rather than periodic boundary conditions.



Planck's spectral density

This computation is far from being just an academic exercise. The resulting partition function contains important information on the statistical properties of the system. This includes not only its entropy, but also the famous Planck law of black body radiation, at the origin of the construction of quantum mechanics itself.

Since the gravitational field, like the electromagnetic field, has two degrees of freedom per point, one expects a similar result.

2 The role of boundary conditions

In the case of gravity, the problem is much more involved since black holes are solutions to complicated non-linear equations. A considerable simplification occurs in 2 + 1 spacetime dimensions where there are black holes but no gravitons. In this case however, gravity is a topological field theory with zero (bulk) degrees of freedom per spacetime point. The above reasoning is obviously far too naive to address the question of a microscopic explanation of the thermodynamic properties of lower-dimensional black holes. What we have learned in three dimensional gravity is that the whole content of the theory is determined by the choice of boundary conditions and/or the topology of space.

In turn, this leads one to study situations in 3 + 1 space-time dimensions where the choice of boundary conditions is indeed relevant. This means in particular that one does no longer consider the large volume limit, but situations where finite size effects become important. As a consequence, the question on the correct choice of boundary conditions for a given problem has to be faced. In the case of electromagnetism, when remembering undergraduate physics courses, one begins to think about perfect conductors and the associated boundary conditions. In terms of the variables used for quantization, they are non trivial in the sense that the vector potential and the electric field along the conductor should satisfy Dirichlet conditions, while their normal components obey Neumann conditions instead. It turns out that this is precisely the set-up of the Casimir effect and that a detailed understanding of this situation might be instructive for the gravitational problem as well.

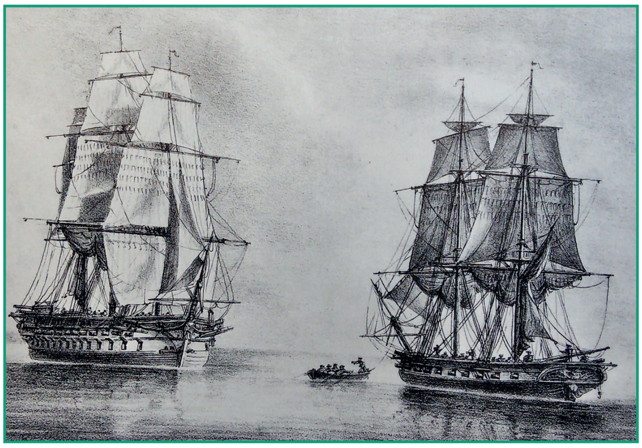
It is both slightly disappointing and very reassuring when one realizes after laborious initial computations that this connection has already been made a long time ago. It underlies much of Bryce DeWitt's 1975 report on quantum field theory in curved spacetime. For instance, as he so eloquently puts it:

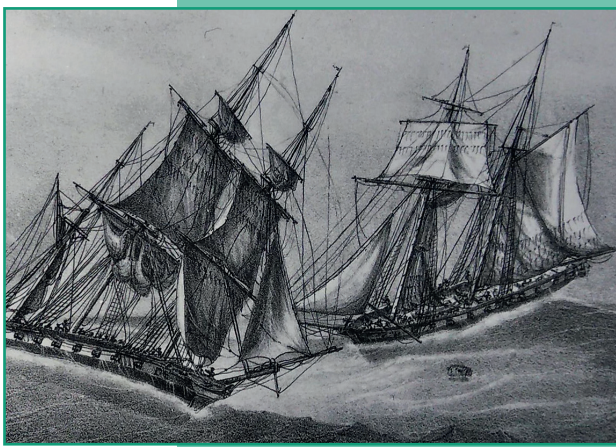
"What boundary conditions should one impose at the edges of a slab-manifold in the case of a scalar field? Setting the field equal to zero there would seem to be a natural procedure. And yet this leaves one with an uneasy feeling. What is the analog of a conductor in the case of a scalar field? In electromagnetic theory we know what a conductor is, both from years of experiment and years of model building. We do not hesitate to impose the standard boundary conditions for the electric and magnetic fields, because we know that the theory is consistent on many levels."

3 Casimir physics

The Casimir effect is the attraction between two neutral, parallel metal plates in vacuum. It is a well-established quantum field theory phenomenon where the force between the plates is due to the boundary conditions imposed on the quantized electromagnetic field. In some modern textbooks, it is used to illustrate the problem of infinities in quantum field theories and how to deal with them.

A popular analogy involves a mysterious attraction between two large ships moored parallel to each other, explained by the difference in wave energy density between the ships and on the see beyond them. Unfortunately, it seems that this is "too good a story to be true", as discussed in a Nature news article: "Does the ghostly Casimir effect really cause ships to attract each other?" [1].





P.C. Caussé, Album du marin

When at the same time, you stumble upon a NASA founded research project in the late 1990's called "Breakthrough Propulsion Physics Program" that suggested to use Casimir sails in order to construct a warp drive, you know you are in trouble [2].

More seriously, the literature on the subject is substantial. It ranges from foundational and theoretical problems in quantum field theory, such as the reality of vacuum fluctuations or various approaches to efficient computation in increasingly complicated geometries, to experimental verification and applications.

Our interest here is in the idealized finite temperature Casimir effect, which is just another name for the problem of computing the partition function of the electromagnetic field subjected to perfectly conducting boundary conditions. This partition function is known to have an intriguing high/low temperature symmetry that allows one to infer the behavior in one regime from the knowledge in the other.

Wormhole travel [3]

[1] https://www.nature.com/news/2006/060501/full/060501-7.html

[2] https://en.wikipedia.org/wiki/Breakthrough_Propulsion_Physics_Program

[3] https://commons.wikimedia.org/wiki/File:Wormhole_travel_as_envisioned_by_Les_Bossinas_for_NASA.jpg

4 Results

Our original motivation consisted in analyzing the contribution of soft degrees of freedom in the Casimir set-up and unearth degrees of freedom that give rise to contributions to the partition function that scale like the area.

In the case of uniformly charged plates, we have been able to show how the classical Gibbons-Hawking contribution originates from the contribution to the partition function of a particle zero-mode. We also have shown that, at low temperature, the leading contribution to the entropy comes from an additional scalar field theory in 2 +1 dimensional that is due to the Neumann conditions in the directions perpendicular to the plates [1], [2]. Contrary to what is implied in these references, it turns out however that these contributions are not related to soft degrees of freedom.

In subsequent work, we have extended the known temperature inversion symmetry of the planar capacitor partition function to full modular invariance, as encountered for instance in 2 dimensional conformal field theory models. Computations have been streamlined by constructing a non-local map between the electromagnetic field with perfectly conducting boundary conditions and a massless scalar field with periodic boundary conditions on the double interval [3].

In the next step, we have constructed the analog of perfectly conducting boundary conditions for linearized gravity and computed the partition function for gravitons in such a Casimir box by the same methods [4]. We are currently writing a review on massless scalar partition functions and modular covariant real analytic Eisenstein series [5]. We also plan to complete the picture by addressing the original question on the role of soft modes in this context. Two other active lines of research involve understanding whether there is an infinite-dimensional symmetry group underlying modular covariance and how to include theta-terms.

5 Perspectives

There is an interesting controversy related to gravitational black body radiation that involves Smolin, Garfinkle-Wald, and Dell. The question is whether a box able to confine gravitons in thermal equilibrium does indeed exist. Another intriguing question is the one raised by F.J. Dyson on whether a graviton is detectable. In order to begin to address such questions, we have to understand better how to include non-trivial interactions in our set-up, either QED type interactions, or their effects through non-idealized boundary conditions appropriate for more realistic materials. Extending our study to curved backgrounds is another step needed to close the loop and explore whether this approach does indeed shed a new light on the problem of black entropy.

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[1] G. Barnich, "Black hole entropy from nonproper gauge degrees of freedom: The charged vacuum capacitor," Phys. Rev. D99 no. 2, (2019) 026007.

[2] G. Barnich and M. Bonte, "Soft degrees of freedom, Gibbons-Hawking contribution and entropyfromCasimireffect,"arXiv:1912.12698 [hep-th].

[3] F. Alessio and G. Barnich, "Modular invariance in finite temperature Casimir effect," JHEP10(2020)134,arXiv:2007.13334 [hep-th].

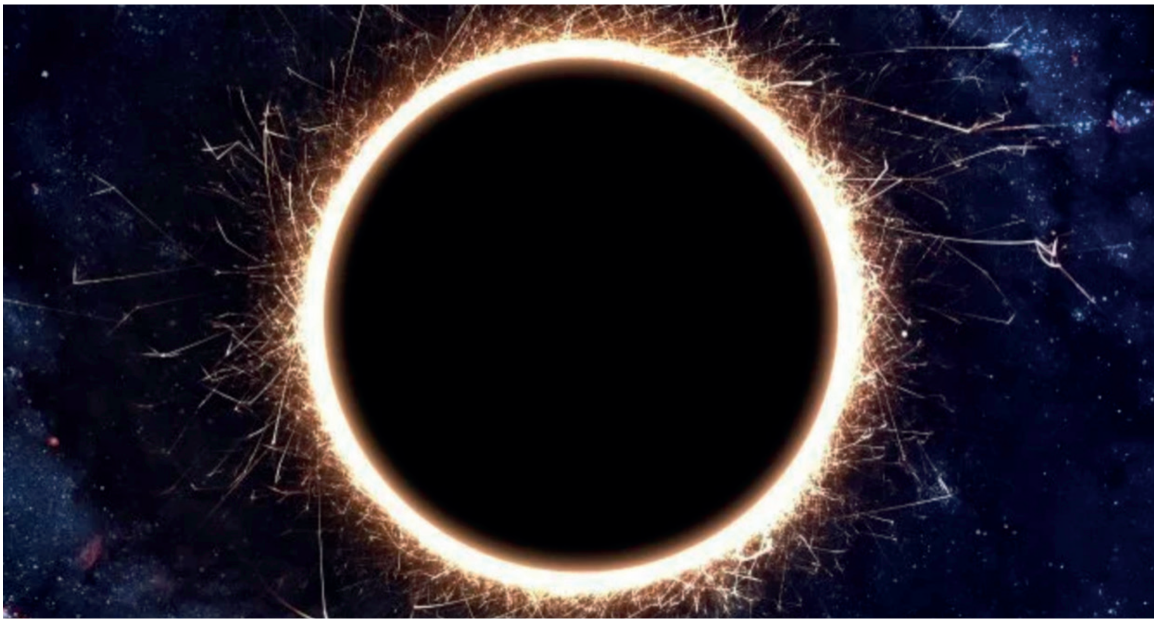
[4] F. Alessio, G. Barnich, and M. Bronte, "Gravitons in a Casimir box,". https://doi.org/10.1007/JHEP02(2021)216.

[5] F. Alessio, G. Barnich, M. Bonte, and A. Kleinschmidt, "Notes on scalar field partition functions and Eisenstein series." in preparation.

Stéphane Detournay
Permanent Research Associate of the «Fonds de la Recherche Scientifique F.R.S.-FNRS» I ULB

Black holes and infinite-dimensional symmetries: beyond Hawking's legacy

The black hole entropy problem constitutes one of the most famous puzzles in contemporary theoretical and gravitational physics. It was raised in the 1970s by Bekenstein, Hawking and colleagues, who suggested that black holes behaved like thermodynamic systems and were in particular endowed with a temperature (the Hawking temperature) and an entropy (dubbed Bekenstein-Hawking entropy). In light of the work of Boltzmann, who interpreted entropy as a measure of the number of microscopic degrees of freedom giving rise to a given macroscopic state (for example, the number of ways in which we can organize the molecules of a gas with given characteristics), this led to the following deep question: if black holes have entropy, what are the microstates that it measures? It is expected that this can only be elucidated within the framework of a microscopic description of the gravitational interaction going beyond that, purely classical, of Einstein's general relativity.



Black Hole Hair

In the mid-nineties, Strominger and Vafa showed how an elegant answer could be given within the framework of string theory for very specific black holes (supersymmetric in dimensions larger than four). Shortly afterwards, Strominger had the determining insight that this result was in fact independent of the details specific to string theory: the counting of states reproducing exactly the Bekenstein-Hawking entropy is based on an emergent symmetry in the vicinity of the horizon of these black holes, of a very particular type, a two-dimensional conformal symmetry. The latter are extremely powerful (in particular, they are infinite-dimensional) and impose strong constraints on the physical observables. They were discovered in the mid-1980s and have applications in fields as diverse as condensed matter physics, statistical physics, and string theory. They also manifest themselves in lower dimensional gravity models, as evidenced by Brown and Henneaux, revealing deep and unexpected connections between theories of gravity in anti-de Sitter spaces (AdS) and conformal field theories (CFT) - the famous AdS / CFT correspondence. These impressive results apply, a priori, only to classes of black holes that are very different from the objects that surround us and populate our universe.

However, over the past decade, various advancements have occurred suggesting that these known symmetries could eventually be relevant for realistic black holes. Hawking's latest article in particular, written in 2018 in collaboration with Haco, Perry, and Strominger, argued that this two-dimensional conformal symmetry is present near the horizon of Kerr black holes such as the one at the center of our galaxy.

The last decade has also seen other important developments. In parallel with the exploration of the role of conformal symmetries for generic black holes (e.g. Kerr/CFT and hidden conformal symmetries), the question has arisen whether, for realistic space-times, other symmetries could come into play. This line of research has brought to light new types of symmetries which, although distinct from two-dimensional conformal symmetries, shared some of their properties. Among them, the warped conformal symmetries, highlighted by my collaborators and myself. A careful analysis of the work of Haco, Hawking, Perry and Strominger has allowed us to observe that these warped conformal symmetries also appear in the vicinity of the horizon of generic black holes, and in fact act in a more natural way. We have shown that the Bekenstein-Hawking entropy of black holes can be accurately reproduced using them, suggesting that they may play an important role in the microscopic understanding of astrophysical black holes [1].

As mentioned above, lower-dimensional gravity models provide a useful arena to address microscopic features of gravity, and we have also been pursuing and exploiting this line of research. We have engineered a gravitational model with a very simple yet powerful symmetry algebra which makes it both tractable and able to address black hole physics [2], of which we are currently uncovering further properties. We devised another model able to capture features of cosmological horizons [3] and identified the holographic dual as very special form of two-dimensional warped CFT. WCFTs are a relatively new and unexplored type of field theories with remarkable properties. In a recent preprint we proposed the counterpart of Quantum Null Energy Conditions for these theories [4].

A last aspect we have been addressing is as follows. String theory possesses a rich variety of symmetries (such as T-duality) relating various space-time geometries. It is interesting to observe that, sometimes, geometries of which we know the holographic dual but otherwise featuring unrealistic features such as a negative cosmological constant can be related to asymptotically flat spacetimes (in a certain sense) through dualities. A natural question one can ask is: what happens to the dual theory under this sequence of dualities on the geometry? Though very hard and untractable in general, we were able, in some specific lower-dimensional examples to identify the dual theory as a particular integrable but irrelevant deformation of a 2d CFT [5].

RESEARCHERS INVOLVED IN THESE PROJECTS:

Apolo (Beijing), Castro (Amsterdam), Song (Beijing and IAS Princeton), Ng (Trinity College Dublin), Wutte (Vienna), Grumiller (Vienna), Riegler (Harvard).

At ULB: Merbis and Ciambelli (postdoctoral researchers), Aggarwal, Somerhausen and Vandermiers (PhD students).

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[3] "Warped Flatland ", Stéphane Detournay, Wout Merbis, Gim Seng Ng, Raphaela Wutte, arXiv :2001.00020, JHEP 2020 (2020) 61.

[4] "Uniformization of Entanglement Entropy in Holographic Warped Conformal Field Theories", Stéphane Detournay, Daniel Grumiller, Max Riegler, Quentin Vandermiers, arxiv :2006.16167.

[5] "TsT, $T\bar{T}$, and black strings ", Luis Apolo, Stéphane Detournay, Wei Song, arXiv :1911.12359, JHEP 06 (2020) 109.

IMAGE: https://www.sciencealert.com/images/articles/processed/BlackHoleEventHorizon_web_1024.jpg

Frank Ferrari I Professor I ULB

Progress in Science is often triggered by the collision of distinct, superficially unrelated fields of research. A paradigmatic example is the discovery of thermodynamical properties in the theory of gravitation, first at the classical level (the "laws of black hole mechanics") and then confirmed at the quantum level (the famous "Hawking radiation") in the 1970s. The relation between gravity and thermodynamics is so surprising and conceptually deep that it has been underlying a large fraction of the work on quantum gravity since then. After half a century of intense research, we still do not fully understand its meaning and consequences.

In recent years, this seminal process of using cutting-edge ideas from seemingly disconnected fields has been vigorously reactivated and has triggered a succession of leaps in our understanding of the quantum properties of black holes. The progress has been both technical and conceptual, using tools and ideas from condensed matter theory (disordered models of strongly correlated electron systems, like the Sachdev-Ye- Kitaev theory), discretized quantum gravity (tensor models), two-dimensional quantum gravity (Jackiw-Teitelboim models), random matrices (topological recursion) and quantum information theory (Ryu-Takayanagi, quantum extremal surfaces). These tools combined have allowed to address some of the deepest questions in the field, including issues related to the information paradox and the consistency of quantum gravity with the unitarity evolution in quantum mechanics.

My work of the past few years is part of this line of research, with contributions on several subjects in the field.

Graphs, tensors and matrices

Physical quantities in quantum theories are typically expressed as a sum over Feynman graphs. In perturbation theory, only a small number of graphs, describing simple microscopic interaction processes, contribute.
This governs for example the physics of the electroweak force (quantum electromagnetic and weak interactions) within the standard model of particle physics. In quantum gravity, however, the relevant physics is fundamentally non-perturbative. This means that one must take into account a very large number of Feynman graphs, truly an infinite number, that must be summed over. This sum is extremely difficult to perform in interesting models.

The precise nature of the relevant graphs depends on the details of the quantum theory one deals with. A prominent class of theories are the so-called matrix models (the gauge theories that are at the basis of the standard model of particle physics are in this class). In this case, the Feynman graphs are in one-to-one correspondence with the discretization of two-dimensional surfaces (or "worldsheets"). Summing graphs thus amounts to summing over discrete surfaces or equivalently to solve a model of random surfaces. But this can also be interpreted as a model of two-dimensional quantum gravity!

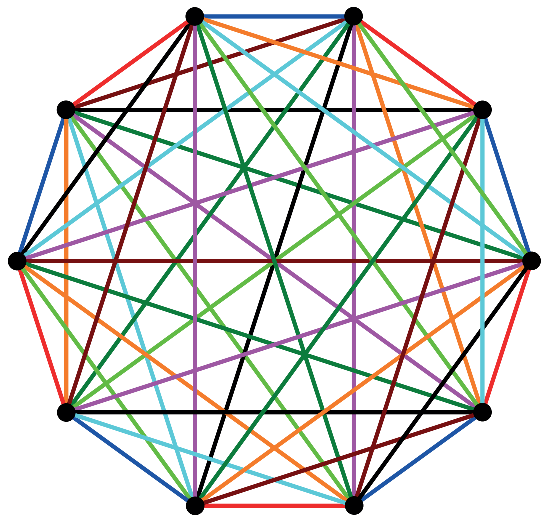

Figure 1: A building block ("vertex") of a melonic graph, from [1]. The drawing has several crucial combinatorial properties: i) it is complete: each vertex (black dot) is related to all the other vertices by edges; ii) it is colored: each edge has a color such that two edges incident on the same vertex always have distinct colors; iii) it is maximally single trace: if one picks any pair of two colors, for instance green and pink, and follow a path in the graph made of edges of alternating colors, say green and pink, then one visits all the edges having these colors before coming back to the starting point.

From this standpoint, it is natural to generalize the matrix theories to new models for which the Feynman graphs map to the discretization of higher dimensional geometries, the dimension four being the obvious privileged example. This programme has been pursued over many years by a fraction of the community in quantum gravity. Much remains to be done to obtain a consistent theory in four dimensions along this line. However, several technical breakthroughs have been achieved in the field, in particular the construction of the large N limit of the so-called "tensor models," whose graphs are associated to higher dimensional discretized geometry. A special class of graphs, called melons, play a crucial role in this set up. Remarquably, the melons can be explicitly summed over, due to simple combinatorial structures associated with them.

One may then reverse the reasoning. If we forget about the interpretation of melons as higher dimensional discretized geometries (the reason for which they were invented!) and come back at the Feynman graph point of view, then melons provide an infinite set of quantum corrections to "tensor" quantum field theories and thus may be used to study non-perturbative effects in these theories. Amazingly, some quantum theories relevant to the description of quantum black holes turn out to be melonic! This is a particularly gripping instance of how fundamental research works: technical tools developed to describe quantum gravity in higher dimensions find applications via the discretization/Feynman graph correspondence to quantum theories designed to describe quantum black holes, which is also quantum gravity albeit in a completely different point of view and number of dimensions!

My collaborators and I have contributed significantly to the development of the above-mentioned graph theoretic techniques and their applications. In particular, the general theory of melonic models relevant to quantum black holes is constructed in [1], where the fundamental notion of the index of a graph is introduced and an important relation with the standard matrix models is also studied in details, following [2]. We have explored several other non-trivial open problems in the field, including notable results on traceless models with reduced symmetries, in a series of other papers.

Phases and black hole formation

We have studied in detail the physics of a paradigmatic example of melonic matrix quantum mechanics in [3] and [4]. Our model has a simple gravitational interpretation. It describes a large number N of particles ("D0-branes") in a region of space of size L, where L is an adjustable parameter. If L is very large, the particles are very far apart from each other and their gravitational back-reaction is negligible. If L is very small (one may set $L = 0$), we have a very large number of particles in a very small region of space. It is natural to guess that below a critical distance L_c, a black hole is created. One of the main results of [3] and [4] is to show explicitly that the quantum system does undergo a strongly coupled phase transition for a critical value L_c of the size. The transition has all the expected properties to describe the creation of a black hole, providing an explicit example (the first, to the best of our knowledge) of a fully quantum description of the phenomenon of gravitational collapse. The quantum model in which this is derived is simplified, in the sense that it does not describe a realistic four dimensional black hole; but it does capture all the essential features of black hole physics.

In more details, at large L, the particles, being very far apart, interact very weakly. The physics is then correctly described by only a small number of Feynman diagrams. The solution is manifestly unitary and interactions are reliably described by standard perturbation theory.

When L decreases, the interactions build up and more and more graphs must be taken into account. The transition at $L = L_c$ is the point beyond which a correct description is necessarily non-perturbative and requires to sum up an infinite set of diagrams. Since these diagrams are melons in our model, the sum can be performed, combining analytic derivations and numerical simulations. The resulting phase has startling properties. Unitarity is violated when the number N of particles is strictly infinite, in a way which is perfectly consistent with the usual information paradox for black holes.

Of course, at finite N, unitarity is restored since our model is quantum mechanical. The violation of unitarity is thus a direct consequence of taking the thermodynamic large N limit. On the gravity side, the $N = \infty$ approximation is equivalent to the semiclassical description of gravity à la Hawking. Another striking aspect of the black hole phase is that it is maximally chaotic, with a Lyapunov expo nent for out-of-time-ordered correlators matching precisely the exponent computed in Einstein gravity.

Two dimensional quantum gravity

The quantum black holes described by melonic models correspond to black holes in certain two-dimensional gravitational theories. They may be obtained in the so-called "near horizon limit" of higher dimensional realistic black holes. They are fascinating theoretical objects on their own, on which the most difficult questions of the quantum theory of black holes can be studied in a mathematically simplified set-up.

The subject of two dimensional quantum gravity is quite old and venerable, the first breakthroughs in the field dating back to the 1980s. Two main classes of theories have been studied. The "Liouville" models describe the general case of two- dimensional quantum gravity coupled to an arbitrary matter conformal field theory. The coupling to non-conformal matter can also be investigated along similar lines. The "topological" models are related to the intersection theory on the moduli space of Riemann surfaces. From the physical point of view, they correspond to an extremely simplified version of quantum gravity, for which the curvature is negative and constant and the space of metrics is finite dimensional.

In between these two classes of models sits the so-called Jackiw-Teitelboim theory. It was formulated long ago but was not investigated in detail until recently, when it was realised that the theory contains the precise ingredients required for the description of the black holes found in melonic models. The Jackiw-Teitelboim theory keeps the constant negative curvature constraint of the topological models, but relax the boundary conditions, in such a way that the space of possible metrics is infinite dimensional, as for Liouville. The resulting physics is then much more interesting.

Many important aspects of the Jackiw-Teitelboim models have already been investigated and several surprising results have been conjectured, with deep consequences for the holographic interpretation of the models. In particular, there is a debate as to whether the models are genuinely quantum mechanical, or rather describe an ensemble of quantum theories over which one must average, in a way reminiscent of the description of disordered systems in condensed matter physics.

This underlies a very deep question in quantum gravity, that goes beyond the description of quantum black holes and motivates our current research activity. As a matter of principle, can we define quantum gravity non-perturbatively from the space-time (bulk) point of view? Or must we use a holographically dual, non-gravitational system, to achieve this goal?

The Jackiw-Teitelboim framework is ideal to investigate this question, but one needs a first-principle approach to the theory to do so. Such an approach has not yet been developed. In [5], we have taken a first step, in constructing a precise gauge theoretic formulation of the theory, akin to the Chern-Simons description of three-dimensional gravity. Many fundamental issues remain open: what is the correct integration measure over metrics in JT gravity? What is the correct microscopic definition of the model? Can we find non-perturbative scaling limits allowing to define the theory non-perturbatively? Answering similar questions played a crucial role for Liouville gravity in the past. In the context of JT gravity, finding the answers may provide important clues for understanding the nature of the holographic correspondence and quantum gravity in general.

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RESEARCH INTERESTS OF SOME DOCTORAL & POSTDOCTORAL RESEARCHERS

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In Pursuit of Symmetries

1. Setting the Stage

Symmetries play a basic role in understanding the elementary constituents of nature. While aesthetically pleasing in different forms of art, the concept of symmetry is indispensable in physics: from decoding complex structures, to relating seemingly different theories, and even theoretically predicting fundamental particles before they were experimentally detected. The pioneering work of Emily Noether in 1918 relating symmetries to conserved charges gave birth to a new era in physics. While global symmetries (which are generated by finite dimensional Lie groups) are associated with conserved charges, local symmetries (also known as gauge symmetries) consist of arbitrary functions of spacetime, and give rise to relations among the equations of motion. In fact, gauge symmetries indicate a 'redundancy' in the physical description of the theory, reflecting the fact that we are working with more number of variables than the physically independent degrees of freedom of the system. Maxwell theory, Yang-Mills theory etc are some notable examples of gauge theories.

However, in the context of analysing the asymptotic behaviour of gravitational fields, it was later realised that some of these 'redundancies' are in fact genuine symmetries, which do change the physical state of the system. Thus began an extremely rich subject of asymptotic symmetry analysis. It was revealed that the algebra of asymptotic symmetries can be larger than the algebra of background isometries, in fact the enhancement can even be infinite dimensional! First explored by Bondi-van der Burg-Metzner-Sachs in the 1960s for asymptotically flat spacetimes in four dimensions, such studies have since been carried out in different spacetime dimensions, on different backgrounds (different values of the cosmological constant Λ), and also incorporating supersymmetry in the picture in some cases.

2. Holography: Gauge-Gravity Duality

An important ingredient in studying gravity is the holographic principle, which is an incredible correspondence between theories of gravity and non-gravitational theories in one lower dimensions. The basic idea is that the physics of a gravitational theory in a D-dimensional spacetime is encoded in a theory without gravity in a (D – 1)-dimensional spacetime, that forms the boundary of the D-dimensional bulk theory. The conjecture was formally proposed by Juan Maldacena in 1997 as the AdS-CFT correspondence. A few decades down the line, the correspondence still remains an active field of research, with widespread applications in constructing dual theories, black hole information paradox, string theory etc.

3. Three Dimensional Gravity

Gravity in three spacetime dimensions comes with it is unique feature: it possesses no local degree of freedom! This makes it a topological gauge theory, all solutions (for a particular Λ) being locally isomorphic. However, this feature does not make 3D gravity trivial, as a large variety of gravitational solutions exists, whenever global topological structures are considered. Locally gauge equivalent solutions can differ by boundary terms, which gives rise to the question of devising suitable boundary conditions: neither too lenient, nor too strict, so as to give interesting physics without bringing in unwanted obstructions. In my research, I have been using the tools of holography to construct two dimensional field theories dual to three dimensional supergravity in the Chern-Simons formalism. The duals can be identified with theories known as Wess-Zumino- Witten models.

An alternative formulation of the boundary action can be considered in terms of the geometric action on coadjoint orbits, making connections with the bulk holonomy. Holonomy of a manifold is a consequence of its curvature. In simple terms, it can be thought of as the extent to which "parallel transport around closed loops fails to preserve the geometrical data being transported". A system with two (or more) boundaries with different dynamics can be coupled through holonomy, resulting in the coupling of the zero modes of the fields on the two boundaries. Along with my collaborators, I am involved in projects concerning these geometric aspects of N-extended three dimensional gravity in asymptotically AdS and flat backgrounds.

4. Four Dimensional Gravity

The BMS symmetry was shown to be the asymptotic symmetry group of asymp- totically flat spacetimes in four dimensions. The analysis was carried out at null infinity. For several years, there was a gap in understanding as the symmetry could not be obtained at spatial infinity. The problem was finally solved in [1] by some suitable modification of the conventional boundary conditions, where the BMS group at spatial infinity was fully recovered. In [2], I have extended this analysis to the case of supergravity by devising suitable boundary conditions on the gravitino at spatial infinity, consistent with the graviton boundary conditions. We were able to show that the boundary conditions are invariant under the super-BMS algebra, and also write down the corresponding surface generators and Poisson brackets. We also discussed the case of extended supergravities.

The most notable feature of our above analysis is that the super-BMS algebra contains only a finite number of fermionic generators. We pondered over the possibility if the algebra can be extended to include an infinite number of fermionic generators. I considered in a collaborative effort [3] the simple linearised models and shown that, by suitably relaxing the boundary conditions, the free Rarita-Schwinger field on a Minkowski background does indeed admit an infinite number of non-trivial fermionic improper gauge symmetries. The compatibility of this new boundary condition with the Lorentz boosts, however, needed the introduction of additional boundary degrees of freedom in the Hamiltonian action. We have then considered the free supersymmetric (1, 3/2) and (2, 3/2) multiplets and shown that rigid supersymmetry is compatible with our boundary conditions, leading to an infinite set of fermionic symmetries. A more ambitious goal is to investigate if similar results still hold when interactions are switched on, that is, in full supergravity. Work on this is underway. All these will hopefully lead us towards a more complete understanding of the quantum theory of gravity.

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Charles Rabideau I Postdoctoral Researcher I VUB

Dynamical chaos is a topic that has beguiled physicists and mathematicians alike over the last half-a-century. In classical physics, a system is chaotic if a small change in initial conditions can cause a big change in the state of the system at a later time. A number of ways to characterise and classify chaotic systems have been developed, but analytic tools for understanding their behaviour are few and far between.

Recently, it has been realised that a quantum mechanical version of chaos exhibits a universal bound. This has led to hope of a universal theory of chaos applicable to theories which nearly saturate this bound and potentially new unifying principles to organise our understanding of this field. These theories are characterised by their holographic nature: they can equivalently be described in terms of a theory of gravity in a larger number of spacetime dimensions. This opens up a whole new tool kit for studying chaos by translating it into the language of this dual gravitational picture.

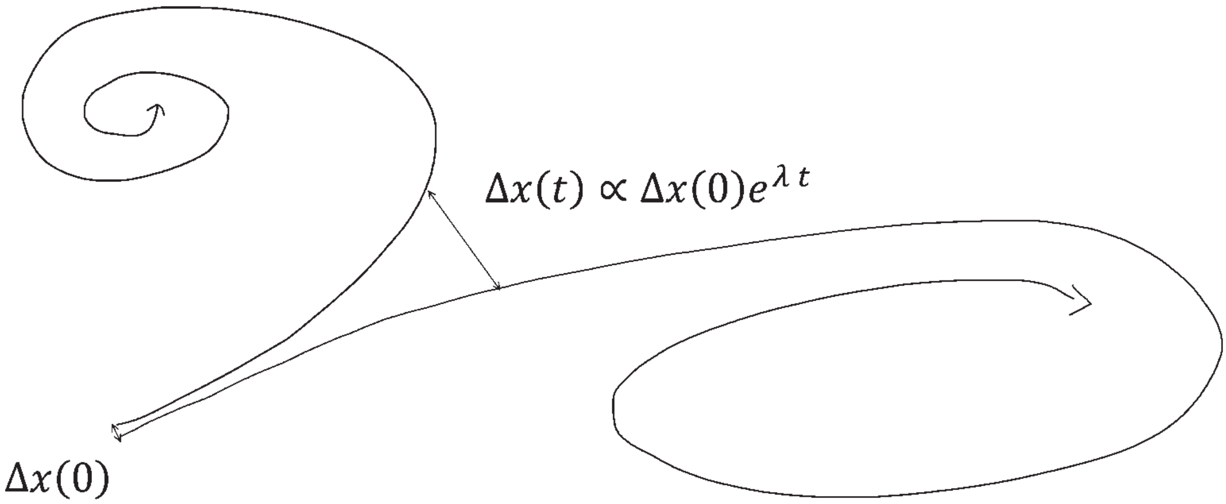
But before going on to this gravitational picture, we should first make sure we understand how this notion of chaos in quantum mechanics aligns with the traditional notions of chaos studied in classical physics. One way to characterise classical chaos is through the Lyapunov exponent which measures the divergence of nearby trajectories. That is, if a butterfly flaps its wings how big of a tornado might later be created? Similarly, the quantum mechanical version is characterised by an exponent that describes the decay of a particular quantity known as an out-of-time-order correlator or OTOC. We studied these two related quantities in the mixed field Ising model and found that in the classical limit of the quantum system the two quantities could indeed be identified, both through analytical computation and explicit numerical verification.

In the dual gravitational framework, the physics of chaos is closely related to that of black holes. In particular, the Lyapunov exponent is directly related to the near horizon geometry of the black hole in question. Black holes are understood to be thermodynamic systems and so in this case we are studying chaos in the thermodynamic limit. Thermodynamic systems involve averaging over the different microscopic arrangements a system that are all described by the same macroscopic state. These arrangements are known as microstates.

The question then naturally arises, since individual systems in the real world are always in a particular state, what effect do these different individual arrangements have on the chaotic properties of a system? In what way does the physics of a black hole geometry reproduce those of such a microstate? And can we learn anything new about chaos or about black holes by relating the physics of the microstates in these two descriptions?

To this end, we studied a gravitational system for which certain black hole microstates have been described in the literature and compared its chaotic properties to those of the dual quantum mechanical system. This required developing new tools on both sides of the equivalence, since the requisite quantum systems were in an unexplored parameter range and the OTOC had not been computed in these types of black holes. Once these tools were developed to work with the averaged macroscopic description, we were able to see that the microstates do indeed closely approximate the results found in the macroscopic description.

I am currently focused on using bottom up techniques from a special class of quantum mechanical theories, known as conformal theories, to better understand the chaotic properties uncovered in gravitational investigations of global quench states and rotating black holes. These techniques allow us to more easily see the manifestations of the dual gravitational description in terms of the language of the quantum mechanical theory. In this way, we hope to better understand how the universal chaotic physics of black holes arises in quantum theories that nearly saturate the chaos bound while also provide a useful cross check on the gravitational results.



In chaotic systems even a small difference in initial conditions can lead to radically different trajectories at late times. The rate at which nearby trajectories diverge is known as the Lyapunov exponent λ.

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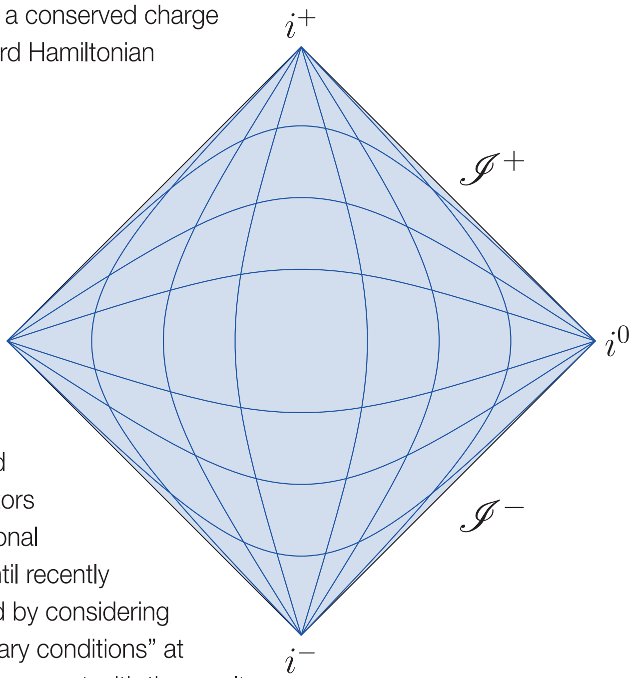
Asymptotic symmetries at spatial infinity

The infinite dimensional Bondi-van der Burg- Metzner-Sachs (BMS) group was shown long ago to be the group of asymptotic symmetries of gravity in asymptotically flat spacetime. It was originally discovered in the asymptotic analysis of gravitational radiation approaching the null infinity of Minkowski spacetime. Recently, remarkable results have shown that the BMS symmetries play an important role in the connection between disparate areas of physics, namely, soft theorems, Ward identities and memory effects, thus leading to the renowned "infrared triangle" that characterizes the dynamics at long distances of all physical theories with massless particles [1].

The BMS symmetries do not only leave invariant the boundary conditions at null infinity, but are also exact symmetries of the theories up to a surface term. Therefore, they should appear in any description, in particular, the one adapted to spatial infinity of Minkowski spacetime where, due to the lack of outgoing flux at spatial infinity, any relevant symmetry can be conveniently generated by a conserved charge that can be determined by standard Hamiltonian techniques [2].



However, analyses at spatial infinity did not exhibit any sign of the BMS_4 algebra, this is because the boundary conditions were to restrictive in order to avoid divergences in the charge generators thus resulting in the finite-dimensional Poincaré algebra [2]. It was not until recently that this discrepancy was resolved by considering appropriate "parity-twisted boundary conditions" at spatial infinity leading to the full agreement with the result at null infinity [3,4]. Remarkably, the analysis disentangles the BMS group from gravitational radiation.

It is in this context that my current work has developed. Recently, it was investigated the asymptotic structure at null infinity of the four- dimensional Pauli-Fierz theory (theory that describes the dynamics of the graviton, hypothetical elementary particle that mediates the force of gravity) [5]. It was shown how Poincaré transformations and improper gauge symmetries merge into the full BMS group as one switches on the gravitational coupling. Interestingly, the free Pauli-Fierz theory and General Relativity show very similar behaviours at spatial infinity. This fact suggests that the free Pauli-Fierz theory could be useful to investigate further extensions in a simpler setup, for instance, the interesting and non-trivial inclusion of logarithmic terms in the asymptotic expansion of the graviton, as well as the still elusive treatment of superrotations symmetries at spatial infinity.

In our journey to unveil how the BMS symmetries emerges at spatial infinity, it is imperative to study the asymptotic symmetries of all the theories that describe the dynamics and interactions of any particles in flat spacetime. Thus, we recently proposed a set of boundary conditions at spatial infinity for four-dimensional standard supergravity, the simplest theory that describes the interaction of the graviton and the gravitino (massless spin-3/2 field), which provides a canonical realization of the finite-dimensional supersymmetric extension of the BMS (super-BMS) algebra of Awada, Gibbons and Shaw [6]. However, group theoretical arguments indicate that extensions of the BMS algebra by an infinite number of fermionic generators exist and indeed, they appear in the asymptotic analysis at null infinity of supergravity in three and four spacetime dimensions. Thus, in order to push in that direction, we provided a consistent Hamiltonian formulation of non-trivial infinite-dimensional fermionic symmetries, through the study of the asymptotic structure at spatial infinity of the free Rarita-Schwinger theory (the theory that describes the dynamics of the gravitino field) as well as the analysis of the supersymmetric spin-(1,3/2) and spin-(2,3/2) multiplets [7].

The remaining question, which is an important part of my current work, is whether one can go beyond the previous supergravity analysis by relaxing the boundary conditions in order to obtain an infinite-dimensional fermionic extension of the BMS algebra. The most interesting enhancement would be the one with a fermionic extension of the BMS algebra such that the fermionic charges are the square roots of supertranslations, in line with the analysis at null infinity. Interesting bounds for the energy could provide an unexplored aspect of the supertranslations symmetries.

There is still a lot to understand and explore in the topic of asymptotic symmetries at spatial infinity. For instance, the extension of the asymptotic analysis to higher dimensions at null infinity has some issues, due mainly to the disparity between even and odd dimensions, in which the latter display unwanted half-integer fractional powers of the radius in the asymptotic expansion, leading to problems with the conformal direction of null infinity. Interestingly, previous analyses at spatial infinity does not show this issue, so that it is crucial for a better understanding, to clarify this discrepancy. Theories describing the dynamic of higher-spin particles (spin greater than 2) have also contributed with interesting results in the topic of asymptotic symmetries. In particular, the analysis at null infinity unveil an infinite-dimensional asymptotic symmetry algebra involving higher-spin supertranslations and superrotations [8]. In view of the foregoing, it is important, and also part of my current work, to extend the asymptotic analysis at spatial infinity for free both bosonic and fermionic higher-spin fields.

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Non-relativistic theories of gravity

Three centuries after Newton's theory, Albert Einstein formulated the theory of General Relativity, which provides a description of gravity in terms of geometry. In the absence of gravity, relativistic field theories are defined on a flat space-time or Minkowski space, where Special Relativity holds. By coupling a field theories to a non-trivial metric introduces curvature, which is the geometrical manifestation of the gravitational field, and whose dynamics is usually described by Einstein's Theory of General Relativity. The understanding of gravity as curvature of space and time was one of the most important changes of paradigm in physics and led to the description of gravitational waves, cosmology and black holes.

On the other hand, we perceive the world as non-relativistic. In practical situations, the relativistic effects of gravity are manifested as corrections to the results that Newtonian (non-relativistic) gravity provides. Examples of this kind of scenario are gravitational waves, gravitational lensing and planetary systems, among others. It is therefore of main importance to develop a good understanding of both relativistic and non-relativistic regimes of physical systems and to have a clear mechanism to pass from relativistic to non-relativistic physics. As it happens in General Relativity, the Newtonian theory of gravity also admits a formulation in terms of geometry. This is not the Remannian geometry that Einstein used to described space-time curvature, but a more exotic one called Newton-Cartan geometry (see Figure 1) where Newtonian time is absolute and Galilean relativity exists in space. In the last years there has been a growing interest in non- relativistic geometry with promising results in the development of many areas of physics such as gravitational waves, fluid mechanics, string theory and condensed matter physics.

Gravity is one of the fundamental forces of nature. Three more fundamental interactions are known, which can be jointly described by quantum field theory. These are the electromagnetic interaction, the weak nuclear interaction and the strong nuclear interaction. The main open problem of fundamental physics is to find unified description of gravity and quantum mechanics. This would provide a microscopic description of gravity, which could, in principle, allow us to understand space-time singularities such as the ones inside black holes or at the origin of the universe. Probably one of the most important breakthroughs in the pursuit of such a unified description is the holographic principle, which postulates that a gravitational theory can be described at the quantum level by a quantum field theory defined at the boundary of space-time, which has a lower dimension. Within this context, Maldacena's conjecture, has played a central role and led to a connection between conformal field theories and supergravity theories in Anti-de Sitter (AdS) space-times. However, if holography is really realised in nature, it seems unlikely that it is a particularity of asymptotically AdS space-times and extensions of these results to others scenarios are needed. Recently, many steps have been taken towards extensions of holography to non-AdS scenarios, such as non-relativistic gravity theories. Furthermore, generalisations of this kind are believed to be important in the in the study of strongly coupled phenomena in condensed matter physics, which could bring interesting setups where the conjecture could be experimentally tested. Along these lines, lower dimensional theories of gravity have been proven useful in the exploration of quantum gravity ideas. One example is Chern-Simons theories, which can used to define topological theories of gravity in three space-time dimensions. Despite not having local degrees of freedom, these theories possess rich boundary dynamics, providing an interesting testing grounds for holographic dualities. Another example that has attracted attention in the recent years are BF theories, which provide theories of gravity in two dimensions and have been holographically linked to low-energy descriptions of a chaotic quantum mechanical many-body system called SYK model.

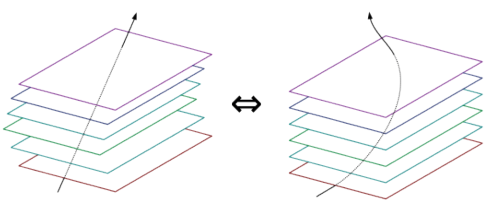

Fig 1. Example of a torsionless Newton-Cartan space-time. Time is absolute and for every value of time there is a spatial slice that can be curved. (Image adapted from https://commons.wikimedia.org/wiki/File:Newton-Cartan-Raumzeit.svg)

In collaboration with Joaquim Gomis, Axel Kleinschmidt and Jakob Palmkvist [1], we have shown that post-Newtonian corrections in particle models can be described by means of an enlarged Minkowski space. This framework provides a way to deal with post-Newtonian corrections while preserving invariance under a non-relativistic symmetry. Moreover, we have used a mathematical technique called Lie algebra expansions to systematically construct Chern-Simons theories of non- relativistic gravity that encode these type of post-Newtonian corrections. Subsequently, in collaboration with Joaquim Gomis and Diego Hidalgo [2], I have constructed the non-relativistic limit of a particular BF theory called Jackiw-Teitelboim gravity, together with a new non-relativistic boundary theory that might be related to a new sector of a complex SYK model. One of my current research lines of focused on understanding quantum aspects of this novel non-relativistic gravity theory as well as to extended these results to include post-Newtonian corrections.

Geometric descriptions of condensed matter systems

The representation of condensed matter systems in terms of quantum field theories is of key importance for increasing their understanding and for finding potential new applications. A primal example is graphene with its relativistic fermion description that opened the way to various new technologies.

In the last years, the discovery of new phases of matter with exotic field content created the need to go beyond standard Quantum Field Theory and General Relativity frameworks in the quest for a better understanding of their underpinnings. The formulation of relativistic quantum field theories on curved spaces has been found to provide effective descriptions of strongly correlated systems. Examples are topological insulators, topological superconductors and chiral superconductors, which can be described in terms of curved geometries. Furthermore, one of the most important physical phenomena in condensed matter physics that can take place in the previously mentioned systems is the quantum Hall effect, namely, the quantisation of the conductance of a two- dimensional electron gas when subjected to strong magnetic fields and low temperatures.

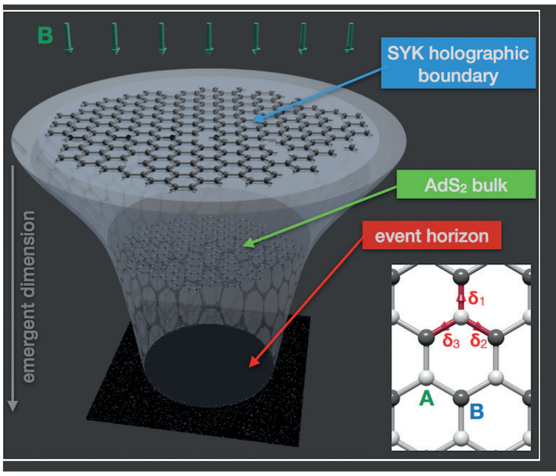

Fig 2. Holographic duality between graphene and a black hole. (Courtesy of M. Franz, University of British Columbia, https:// physicsworld.com/a/black-hole-hologram-appears-in-a-graphene-flake/)

In the recent years, there has been intensive research on geometric descriptions of the Quantum Hall effect in terms of non-relativistic gravity and Newton-Cartan geometry. The reason is that, as many systems in condensed matter physics, this phenomenon is intrinsically non-relativistic but at the same time it involves non-trivial geometry when the system is put on a curved space. Along these lines, in collaboration with Giandomenico Palumbo, I have constructed Geometric model for the Fractional Quantum Hall Effect using an extension of the Euclidean algebra called Nappi-Witten symmetry [3]. This model can be obtained from a three-dimensional non-relativistic gravity theory based on an extension of Newton-Cartan geometry to include a constant electromagnetic field. Furthermore, this non-relativistic gravity theory can be used to obtained the chiral degrees of freedom living at the boundary of a curved sample, which characterise the Fractional Quantum Hall Effect.

As previously stated, these kind of systems can provide experimentally testable examples the holographic conjecture. Indeed, recent experimental studies have shown that under certain conditions, electrons moving on graphene layers can be described by the SYK model. This set up can be used to holographically construct a black hole in a two-dimensional AdS space (see Figure 2). In collaboration with Giandomenico Palumbo and Jiannis Pachos, we have constructed field theories that capture the low-energy dynamics of interacting electrons in a certain type of topological insulators [4]. Together with Jiannis Pachos, I am currently developing a generalisation some of these results to model interacting electrons on graphene layers using gravitational theories. This might provide a testable model for certain features of quantum gravity where holography could be realised.

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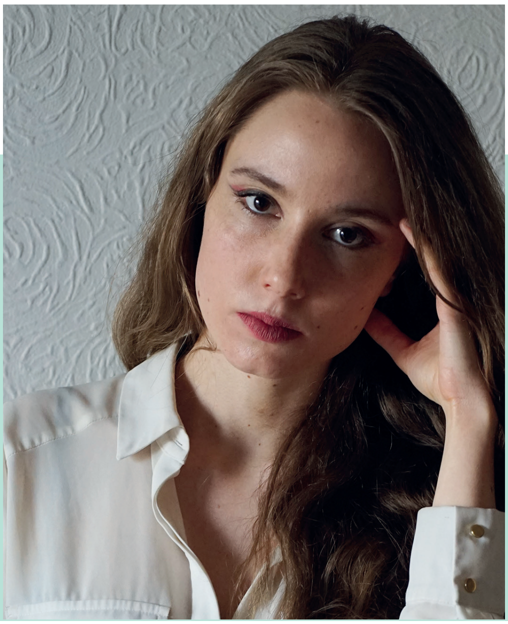


Sofia Zhidkova I Doctoral Researcher I VUB

> “The outstanding challenge of theoretical physics is to find the ultimate description of the laws of nature, valid at all scales and energies, and unifying quantum theory with gravity.”

The outstanding challenge of theoretical physics is to find the ultimate description of the laws of nature, valid at all scales and energies, and unifying quantum theory with gravity. At small scales, the Standard Model of elementary particle physics provides a remarkable explanation of the fundamental constituents of matter and offers some of the most accurate agreements with experiment in modern science. Far removed from the subatomic scale, Einstein's theory of General Relativity predicts the behaviour of gravitational effects throughout the universe, most recently confirmed via the first direct detections of gravitational waves.

However, neither of these theories are complete. In the Standard Model, for instance, we do not know how to deduce the masses of the elementary particles (and other parameters in the theory) from first principles. Furthermore, we do not know how to combine the two. The Standard Model is a quantum mechanical theory, while General Relativity is not.

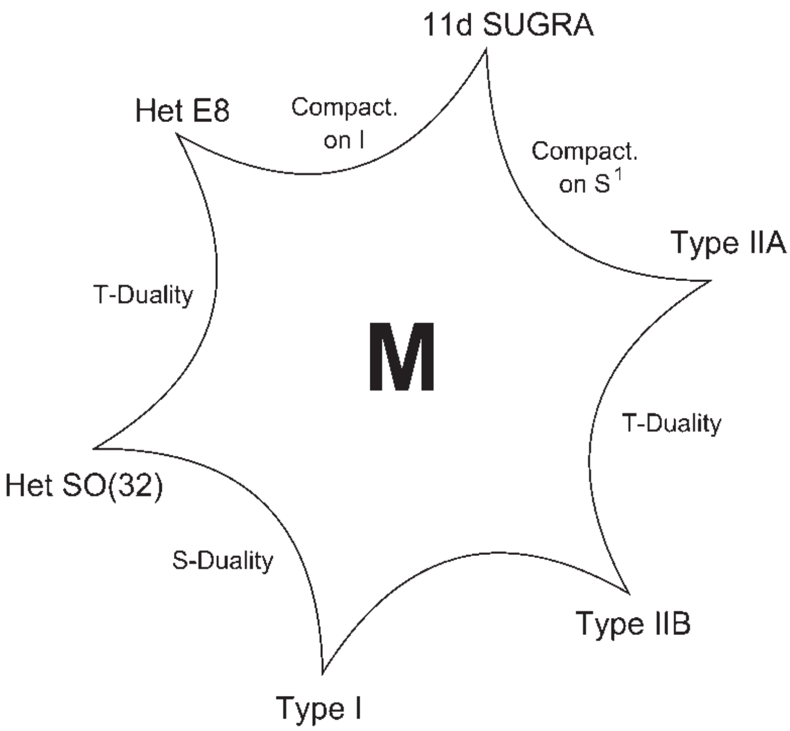
String theory is the most compelling candidate for such a theory, as it provides a natural mechanism to unify gravity and quantum theory. Strings are extended objects, and so behave very differently to elementary particles, which can only probe the universe one point at a time. This leads to a spectrum of unexpected "dualities" that tell us that very different string theory models are in fact the same, and point the way to the existence of a more fundamental description containing not only strings but other extended objects, all of which are transformed into each by duality.

Dualities play an important role in physics, they relate two absolutely different physical models to each other (a good example of a duality in statistical physics is the well-known Kramers-Wannier duality, which relates the square-lattice Ising model at low temperature to the one at high temperature).

String theory experiences many different types of dualities. The simplest string duality follows from the fact that strings have length. As a result they experience geometry very differently of a particle. For instance, a string does not distinguish between winding around large circle of radius R and moving around a small circle of radius $1/R$ (or vice versa). We say that the large and small circle descriptions of the geometry are dual. This is known as T-duality.

Other dualities involve the coupling *g* determining the strength of string-string interactions. Some string theories at strong coupling, *g* large, are the same as others at weak coupling, *g* small. This is called S-duality.

Combining these basic dualities, will lead to an interesting web of connections between string theories (see Fig 1), that tells us we should think of all different string theories as being different dual descriptions of a single underlying more fundamental theory - the M-theory.



As well as strings, M-theory contains other extended objects with more dimensions than a string (for instance, membranes which are extended in two spatial directions), and duality can transform strings into these branes. However, the geometrical interpretation of dualities in M-theory is still mysterious, since the physics of membranes is not well understood, for example quantisation is extremely difficult.

In my project I focus on developing our understanding of a generalised version of dualities in M-theory, using novel geometrical techniques beyond our usual point particle intuition, including the possibility that more general versions of known dualities exist, and implement that in generating new solutions. Apart of that, I will investigate links between the symmetries that appear in quantum field theories, which describe elementary extended objects (branes), and the geometry of dualities from the perspective of how an extended membrane sees the world.

Martin Bonte | Doctoral Researcher | ULB

Thermodynamics and black holes

Thermodynamics was developed in the nineteenth century to study the efficiency of steam engines. In this framework, the entropy is a kind of measurement of disorder in a physical system, and the second of the four fundamental laws of thermodynamics states that it should always increase.

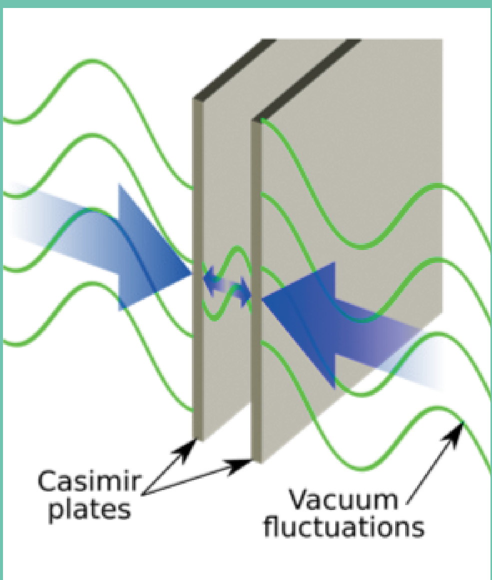
Later, in the beginning of the twentieth century, Albert Einstein formulated the equations of general relativity. Karl Schwarzschild found a solution to these equations, known as the Schwarzschild metric, describing the space-time surrounding a black hole.

These are two initially unrelated branches of physics, but Jacob Bekenstein confronted them in 1972, and suggested that black holes should have an entropy, otherwise throwing an object in it would decrease the total entropy of the universe. Because the mass of a black hole scales as its area, so does his entropy. This is a quite unusual behaviour for the entropy: for all other systems, it is an extensive quantity (proportional to the volume of the system)! The Gibbons-Hawking prescription gives a way to find this entropy from the path-integral formulation of the gravitational partition function.

On the other hand, within the framework of statistical physics, the entropy of a system can also be expressed in terms of the number of indistinguishable microstates corresponding to the current macrostate of the system.
Then comes naturally the question of which are the microstates of a black hole responsible for its entropy.

This is the topic we are currently working on, with Francesco Alessio and my thesis advisor, Glenn Barnich. Our initial idea was to find in the Casimir physics which degrees of freedom could explain the black hole entropy.

Casimir Physics



The Casimir effect was first theoretically described in 1948 by Hendrik Casimir. It states that two uncharged perfectly conducting plates in the vacuum attract each other. This effect is not due to the classical electrostatic interaction of the plates, but rather to the quantum behaviour of the electromagnetic field in a cavity with perfectly conducting boundaries.

When computing the partition function of such a system, there is a piece scaling as the volume between the plates, and another scaling as the area of the plates. The former is usually discarded in this context, since its presence is not due to the plates, and it is therefore irrelevant for this situation. The force attracting the two plates together can be derived from the latter piece, in agreement with experimental observations.

The literature on the subject is substantial, and a lot of knowledge is already available. From a theoretical perspective, one intriguing result is the inversion symmetry of the partition function, which allows to infer the behaviour of the system at low temperature from the one at high temperature, and vice-versa.

Our progress

Our original motivation was to find in the very comprehensive literature of the Casimir effect the degrees of freedom responsible for the area scaling of the partition function. In this sense, the electromagnetic field in a spacetime with boundary is a toy-model for the gravitational field of a black hole.

We recovered the result of the Gibbons-Hawking prescription from the partition function of a particle zero-mode existing in the electromagnetic spectrum between the plates. We found in addition which degrees of freedom give the leading contribution at low temperature to the partition function of this system [1], [2]. There was a hope to relate this to soft degrees of freedom, but it turned out there was not any link, contrary to what is announced in these references.

We passed next to the similar computation of the partition function for the gravitational field in the linearised limit, in the same geometrical setup [3]. We choose consistent boundary conditions and showed that the degrees of freedom are the same than for the electromagnetic field with perfectly conducting plates, which means that the partition functions are formally equal.

The next step of this project is to compute the partition function of the electromagnetic field in a black hole geometry. This is again a toy-model for the computation of the partition function of the linearised perturbations of the gravitational field around a black hole geometry, from which it could be seen why the entropy is not extensive in this case.

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APPRAISALS AND PRIZES | THESES DEFENDED IN 2020

Appraisals and Prizes

- Ms Sofia Zhidkova obtained an "aspirant" doctoral fellowship from the Fonds Wetenschappelijk Onderzoek – Vlaanderen (FWO).
- Alberto Mariotti and Alexander Sevrin obtained an iBOF network of excellence grant "Unlocking the Dark Universe with Gravitational Wave Observations: from Quantum Optics to Quantum Gravity", a concerted initiative involving the VUB, KU Leuven, UGent and UAntwerpen to boost gravitational wave research in Flanders.

Thesis defended in 2020

- Romain Ruzziconi I ULB
  "On the Various Extensions of the BMS Group"
  15 June 2020 (thesis advisor: Professor Glenn Barnich).

TALKS AT CONFERENCES, SEMINARS AND SCHOOLS

Alex S. Arvanitakis

Double field theory via homotopy transfer
Exceptional Geometry Online Seminar Series, Potsdam, Germany – 6 November 2020.

Glenn Barnich

Soft degrees of freedom, Gibbons-Hawking contribution & entropy Casimir effect
Radboud University, Nijmegen, The Netherlands
14 January 2020.

Symmetries and conservation laws in gauge field theories
11h PhD lecture course, Dutch Research School of Theoretical Physics, Dalfsen, The Netherlands
28-31 January 2020.

Notes on gauge theories with boundary conditions
A Gauge Summer with BV: Online conference, University of Zürich, Switzerland – 24 June 2020.

Gravity with boundary conditions
Panel discussion presentation, Quantum Gravity 2020, Perimeter Institute online conference – 14 July 2020.

Soft degrees of freedom, Gibbons-Hawking contribution, entropy & modular invariance in Casimir effect

- Centro de Estudios Científicos, Validivia, Chile, Virtual theoretical physics seminar – 13 August 2020.
- Workshop on Quantum fields and nonlinear phenomena, University of Craiova online conference, Poland
  29 September 2020.

Soft degrees of freedom, entropy & modular invariance in Casimir effect
Université de Nancy, France, Workshop on Statistical Physics and Low Dimensional Systems
5, 6, 7 October 2020.

Introduction to classical and quantum gauge theories
9h PhD online lecture series, Beijing National University and Tianjin University, China
8, 12, 15, 19, 22, 26 October 2020.

Chris Blair

Doubled and non-relativistic string theory
Chulalongkorn University, Bangkok, Thailand
21 January 2020.

Non-relativistic duality and TTbar deformations
Exceptional Geometry Seminar Series, online
22 May 2020.

Non-Lorentzian Generalised Geometry: From DFT and ExFT to SNC and TNC
Non-Lorentzian Zoom Events, online – 8 July 2020.

Exploring Exceptional Drinfeld Geometries
Integrability, Dualities and Deformations seminar series, online – 7 October 2020.

Simone Blasi

Little hierarchy and compositeness
EOS be.h Winter Solstice Meeting, Brussels, Belgium
16 December 2020.

Luca Ciambelli

Dual Fluid of the Bondi Gauge

- Universidad de Buenos Aires, Argentina
  13 February 2020.
- Universidad Andres Bello, Santiago, Chile
  25 February 2020.

TMG with Compere-Song-Strominger boundary conditions
Université libre de Bruxelles and Instituts Solvay, Bruxelles, Belgium – 23 November 2020.

Andrés Collinucci

U(1)'s in 5d and 3d, Higgs branches and algebraic geometry
Imperial College, London, UK – 11 September 2020.

Geoffrey Compère

Some physics behind supertranslations and superrotations
Saclay, Paris, France – 19 February 2020.

BMS: The classical, the quantum, the gravitational wavy and the cosmological
UvA, Amsterdam, The Netherlands – 24 March 2020.

BMS and microstates: some thoughts
Saclay conference on Black hole microstates, Paris, France
8 June 2020.

The BMS group in (A)dS

- Nordic HET seminar, Stockholm, Sweden
  16 June 2020.
- ICTS String Seminars, Pune, India
  19 June 2020.
- 4th International Conference on Holography, String Theory and Discrete Approach, Hanoi, Vietnam – 5 August 2020.

Signatures of High Spin in Gravitational Waveforms & Flux-balance laws
Southampton STAG Seminar, Southampton, UK
5 November 2020.

Ben Craps

Quantum chaos, thermalization and holography
CY Cergy Paris University, Cergy, France – 6 February 2020.

Time-periodicities in holographic CFTs
Steklov Mathematical Institute, Moscow, Russia, online
4 May 2020.

Microstates and chaos
Saclay Gif-sur-Yvette France online – 9 June 2020.

Slow scrambling in extremal BTZ and microstate geometries

- Rencontres théoriciennes, Paris, France, online
  22 October 2020.
- Saclay, Gif-sur-Yvette, France, online – 9 December 2020.

Marine De Clerck

Quantum chaos in a quenched state
Gong show, Trinity College Dublin, Ireland, online
24 August 2020.

Stéphane Detournay

The Physics of Quantum Information
LUCA School of Arts, Brussels, Belgium
30 September 2020.

Trous noirs, un tour d'horizon : le prix Nobel de physique 2020
Royal Academy of Belgium, Brussels, Belgium
14 November 2020.

Shedding light on black holes
Full Circle, Brussels, Belgium – 19 November 2020.

Oscar Fuentealba

Asymptotic structure of the Rarita-Schwinger theory in 4D at spatial infinity
Université Libre de Bruxelles, Brussels, Belgium
24 November 2020.

Marc Henneaux

Cosmological billiards and near-singularity symmetries: a review
Talk given at the workshop: "Gravitational Holography", Kavli Institute for Theoretical Physics, University of California at Santa Barbara, USA – 4 February 2020.

Symétrie et Gravitation
Leçon inaugurale at Collège de France, Paris, France
5 March 2020.

The antifield-BRST approach to (gauge) field theories: an overview
Talk given (online) at the workshop: "Higher Structures and Field Theory", Erwin Schrödinger International Institute for Mathematics and Physics (ESI), Vienna, Austria
23 September 2020.

The challenge of quantum gravity and some ideas currently pursued to overcome it
École Normale Supérieure, Paris, France
10 November 2020.

Laura Lopez-Honorez

When Cosmology meets Feebly Interacting dark matter Particles
Virtual Marie Curie colloquium, MPIK, Heidelberg, Germany, online – 20 April 2020.

(Not even) Feebly coupled Dark Matter as Non-Cold Dark matter
University of Sidney, Australia, online – 2 July 2020.

(Not even) Feebly Interacting Massive Particles as Non-Cold Dark matter
Sao Paulo, Brazil, online – 8 December 2020.

Sucheta Majundar

Asymptotic symmetries of linearized gravity
International Solvay Institutes, Brussels, Belgium
23 November 2020.

Alberto Mariotti

Low energy SUSY breaking and gravitational waves
GW meeting conference, Zoom, Belgium
27 October 2020.

Javier Matulich

Hypergravity
Universidad Católica de la Santísima Concepción, Concepción, Chile – 9 January 2020.

Asymptotic symmetries at spatial infinity
Université Libre de Bruxelles, Brussels, Belgium
23 November 2020.

Wout Merbis

Boundary actions for three dimensional gravity
- Technical University of Vienna, Austria
  13 February 2020.
- University of Amsterdam, the Netherlands
  18 February 2020.

Many-body stochastic systems on complex networks
University of Amsterdam, the Netherlands
26 November 2020.

Turmoli Neogi

Asymptotic realization of the super-BMS algebra at spatial infinity
Virtual Solvay Workshop on "The asymptotic structure of spacetime", Brussels, Belgium – 24 November 2020.

Ali Seraj

BMS flux balance equations and applications for Gravitational waves
- COST action meeting on Gravitational Waves, Black Holes and Fundamental Physics, IFPU, Trieste, Italy
  15 January 2020.
- Institut d'Astrophysique de Paris (IAP), France
  10 March 2020.
- Belgian GW meeting Brussels, Belgium
  27 October 2020.

Flux-balance laws at null infinity
Solvay workshop on "The asymptotic structure of spacetime", Brussels, Belgium – 24 November 2020.

Alexander Sevrin

Gravitational Wave Physics at the VUB
Belgian Gravitational Wave Meeting, Zoom, Belgium
27 October 2020.

Gravitational waves, yet another link between Leuven and Brussels
Research Day @ ITF, Zoom, Belgium – 16 December 2020.

PUBLICATIONS

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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 2020, the prizes have been awarded to:

- **Lieven Bekaert** (Ilya Prigogine Prize VUB)
- **Caroline Rode** (Ilya Prigogine Prize ULB)

- **Cédric Schoonen** (Robert Brout Prize ULB)
- **Joeri Lenaerts** (Robert Brout Prize VUB)

NONLINEAR PHYSICAL

GROUP OF PROFESSOR ANNE DE WIT | ULB

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Reda Tiani

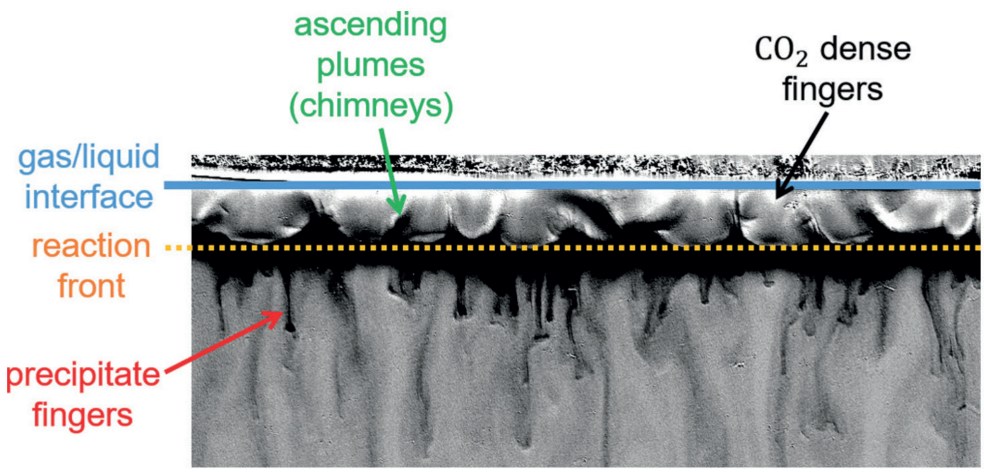
RESEARCH SUMMARY

Effect of mineralization reactions on CO_2 convective dissolution

Carelle Thomas, Sam Dehaeck and Anne De Wit

To analyze the influence of a precipitation mineralization reaction between dissolved CO_2 and calcium ions on the convective transfer of CO_2 towards an aqueous phase, the convective dissolution of CO_2 into aqueous solutions of calcium hydroxyde [$Ca(OH)_2$] of various concentrations has been studied experimentally. The reactor consists in a Hele-Shaw cell made of two glass plates separated by a thin gap and containing the aqueous solution. Gaseous CO_2 dissolves in the aqueous host phase from above. We have shown that different precipitation patterns develop in the aqueous solution depending on the concentration of the reactant in the host phase. Precipitation leads to vigorous convective mixing in the host phase and sedimentation of solid particles of calcium carbonate ($CaCO_3$) down to the bulk of the reservoir (see Fig.1). This mineralization reaction is favorable for the safety and efficiency of the sequestration process of CO_2 in brine as it enhances the flux of CO_2 towards the host phase and favors its convective sinking towards the bottom of the aquifer.

Fig.1: Zoom on a precipitation front obtained when CO_2 dissolves in a host aqueous layer containing calcium ions. Solid $CaCO_3$ particles are formed at the reaction front and sink convectively towards the bottom of the host phase.



CHEMISTRY UNIT

Rectilinear and radial advection of A + B → C reaction fronts give different yields

Fabian Brau and Anne De Wit

In the presence of advection at a constant flow rate in a rectilinear geometry, the properties of planar A + B → C reaction fronts feature the same temporal scalings as in the pure reaction–diffusion case. In a radial injection geometry where A is injected into B radially at a constant flow rate *Q*, temporal scalings are conserved, but the related coefficients depend on the injection flow rate *Q* and on the ratio γ of initial concentrations of the reactants. We have shown that this dependence of the front properties on the radial velocity allows us to tune the amount of product obtained in the course of time by varying the flow rate. We have compared theoretically the efficiency of the rectilinear and radial geometries (see Fig.2) by computing the amount of product C generated in the course of time or per volume of reactant injected. We have shown that, in some cases, the total amount of C produced is larger in the radial geometry, even if the production of C per unit area of the contact interface between the two reactants is larger in the rectilinear case. This comes from the fact that the length of the contact zone increases with the radius in the radial case, which allows us to produce *in fine* more product C for a same injected volume of reactant or in reactors of a same volume than in the rectilinear case. These results pave the way to the geometrical optimization of the properties of chemical fronts.

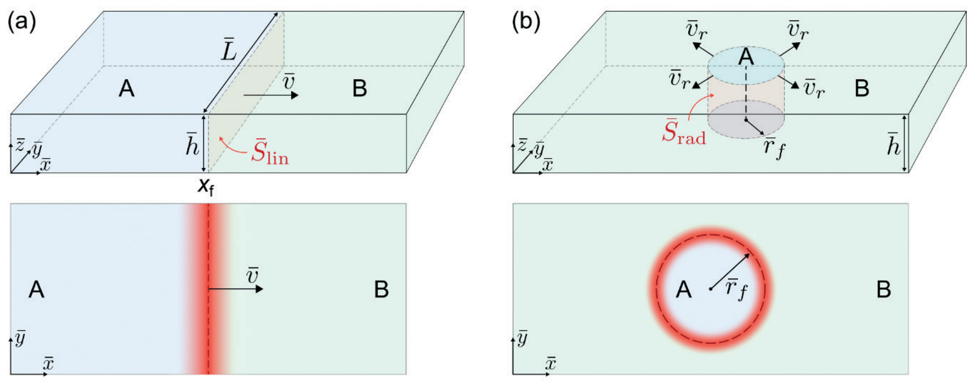


Fig.2: Comparison between A+B->C fronts in (a) rectilinear and (b) radial geometries

Effects of radial injection and solution thickness on the dynamics of confined A + B → C chemical fronts

Anne De Wit and Fabian Brau

The spatio-temporal dynamics of an A + B → C front subjected to radial advection has been investigated experimentally in a thin solution layer confined between two horizontal plates by radially injecting a solution of potassium thiocyanate (A) into a solution of iron(III) nitrate (B). The total amount and spatial distribution of the product $FeSCN^{2+}$ (C) have been measured for various flow rates *Q* and solution thicknesses *h*. The long-time evolution of the total amount of product, n_C, is compared to a scaling obtained theoretically from a one-dimensional reaction–diffusion–advection model with passive advection along the radial coordinate r. We have shown that, in the experiments, n_C is significantly affected when varying either Q or h but scales as $n_C \sim Q^{-1/2} V$ where *V* is the volume of injected reactant A provided the solution thickness *h* between the two confining plates is sufficiently small, in agreement with the theoretical prediction (Fig.3). Our experimental results also evidence that the temporal evolution of the width of the product zone, W_C, follows a power law, the exponent of which varies with both Q and h, in disagreement with the one-dimensional model that predicts $W_C \sim t^{1/2}$. We have shown that this experimental observation can be rationalized by taking into account the non-uniform profile of the velocity field of the injected reactant within the cell gap.

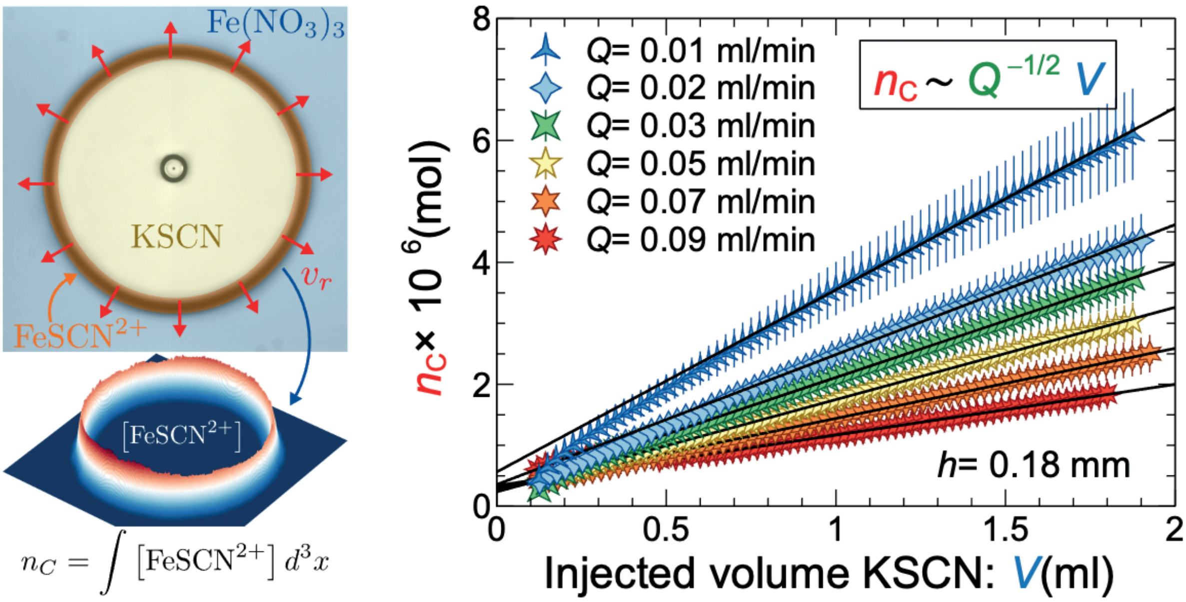


Fig.3: Propagation of a reaction front of a bimolecular reaction A+B->C in a radial injection. The total amount of product n_c scales linearly with the injected volume.

Confined bimolecular reactions

Reda Tiani and Laurence Rongy

We are currently investigating the behavior of $A + B \rightarrow C$ fronts interacting together via a layer of reactant confined between them. We have shown that new phenomena can emerge in those ubiquitous bimolecular reaction-diffusion (RD) systems when finite-size effects are included, such as collective motion. The front-front interaction is seen to change from an attractive type to a repulsive one as the initial distance between the fronts increases. Since previous theories of front propagation fail to predict those phenomena, we have developed a new interpretation of front propagation that paves the way into a general theory of N (arbitrary) interacting fronts. Unexpectedly, a scaling law emerges in this context that suggests the possibility to extract kinetic rate constants from experiments, control front direction, and revisit periodic precipitation patterns. Those results are therefore expected to trigger new types of experiments on bimolecular RD systems.

Modeling wound-healing dynamics

Alexis Grau Ribes, Yannick De Decker and Laurence Rongy

The mobility of biological cells and their adhesion properties play crucial roles in the dissemination of cancer. The intracellular processes (gene expression, concentrations of chemicals inside the cell, etc.) are expected to affect the transport properties but the feedback of cellular composition on cell motion is rarely accounted for. We have recently derived a multiscale reaction-diffusion model for the motion of cells where the transport properties are calculated *in situ* depending on the genetic expression in each cell. Our model successfully reproduces wound-healing cell migration experiments showing the influence of a key protein, E-cadherin, on cell mobility. That protein mediates cell-cell adhesion in epithelial tissues and its loss is associated with tumor progression. By connecting the mobility of cells and gene expression dynamics inside the cells, our model is able to establish a connection between E-cadherin and cell transport properties. The spatial profiles of cell density can be modeled for *different* experimental conditions with a *unique* set of parameter values instead of resorting to ad hoc sets of parameters.

On the Fokker–Planck approach to the stochastic thermodynamics of reactive systems

Yannick De Decker, Grégoire Nicolis

Stochastic thermodynamics is an extension of classical nonequilibrium thermodynamics that aims at including the effect of fluctuations occurring at small scales. In many cases, the starting point of such approaches is a Fokker–Planck equation for the probability density associated to the underlying stochastic variables. It is known that for chemically reactive systems, the equation for entropy production derived in this framework is not consistent with its macroscopic counterpart. It moreover also differs from the expression obtained with the master equation, from which the aforementioned Fokker–Planck equation derives.

In this work, we developed an alternative approach to stochastic thermodynamics whose expression for entropy production converges to the results of classical thermodynamics in the macroscopic limit, and is moreover consistent with expressions obtained with the master equation. We showed, in particular, that the previous approaches to stochastic thermodynamics rely on the hypothesis that thermodynamic fluxes are proportional to the corresponding thermodynamic forces. While this is a reasonable assumption for mass or heat diffusion, the rates of chemical reactions are known to depend exponentially on the affinities. This explains why previous approaches worked well for transport phenomena, but nor for reactive systems.

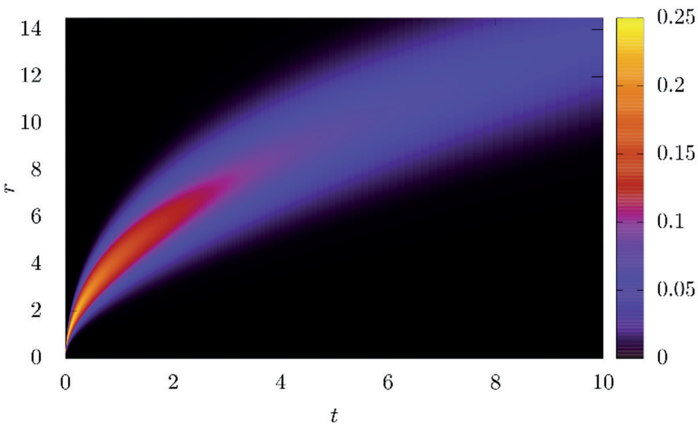
Alessandro Comolli | Postdoctoral Researcher | ULB

I joined the Nonlinear Physical Chemistry (NLPC) unit in 2018 as a postdoctoral fellow to study the dynamics of reaction fronts from theoretical and numerical perspectives.

Depending on the nature of the reactants and the products, reaction fronts can describe a wide variety of phenomena, including combustion, infectious disease spreading, precipitation patterns formation or processes in geochemistry, to cite a few.

The interplay between physical and chemical processes gives rise to complex reaction fronts dynamics and the formation of a large variety of self-assembled structures, the properties of which vary according to the geometry of the system.

Figure 1: Numerical space-time plot of the dimensionless concentration of C.



Systems where a reactant is injected radially into the other at a constant flow rate allow us to quantify the impact of non-uniform advection on the front dynamics. Specifically, I study A+B→C and autocatalytic reaction fronts undergoing a radial laminar flow in a confined geometry, which is a model for reactive transport in Hele-Shaw cells or porous media. Figure 1 shows an example of the temporal propagation of the product C of the reaction in presence of a flow.

In addition, to study the formation of different patterns in radial reactive fronts, I consider autocatalytic reactions when the two species have different mobility properties. Under these conditions and with no need for any hydrodynamic coupling, autocatalytic fronts exhibit transverse instabilities, i.e. front deformations orthogonal to the direction of propagation, which form a variety of patterns.

Appraisals and Prizes

- Anne De Wit has been awarded the "Prix Adolphe Wetrems en Sciences mathématiques et physiques de l'Académie Royale des Sciences, des Lettres et des Beaux-Arts de Belgique".
- Anne De Wit has been elected Member of the "Fellowship Committee" of the Fluid Dynamics Division of the American Physical Society.
- Jean Gillet has been awarded for his Master thesis:
  - > The 2020 annual prize of the Société Royale de Chimie (SRC);
  - > The Solvay Prize;
  - > The First Prize of the "Association des Diplômes de la Faculté des Sciences de l'Université libre de Bruxelles" (A.Sc.Br).
- Jean Gillet has obtained a FRIA fellowship to do a PhD thesis under the supervision of L. Rongy and Y. De Decker.
  He will study the effect of transport on the emergence of homochirality.
- Alessandro Comolli has obtained a Marie Skłodowska Curie COFUND action Individual Postdoctoral Fellowship to work at the Université libre de Bruxelles.

PhD theses defended in 2020

A. Grau Ribes

"Mathematical models of transport phenomena in biological tissues"
(Supervisors: Professors L. Rongy and Y. De Decker).

J.-F. Derivaux

"Stochastic thermodynamics of transport phenomena and reactive systems: an extended local equilibrium approach"
(Supervisor: Professor Y. De Decker).

Master theses defended in 2020

L. Amamdzian

"Effets de courbure sur la dynamique de fronts A + B → oscillateur : étude expérimentale"
(Promotor: Professor A. De Wit).

A. Bouhy

"Modélisation de l'influence des pertes de chaleur sur la dynamique d'un front de polymérisation"
(Promotor: Professor L. Rongy).

J. Gillet

"Stochastic behaviour of chiral co-polymerisation processes" (Promotor: Professor Y. De Decker).

G. Palumbo

"Déformation d'une plaque élastique par une goutte de liquide : étude variationnelle des effets élasto-capillaires dans un modèle bidimensionnel"
(Promotor: Professor F. Brau).

TALKS AT CONFERENCES, SEMINARS AND SCHOOLS

Alessandro Comolli

- "Dynamics of A+B→C reaction fronts under radial advection in three dimensions"
  Workshop "Mixing in Porous Media", Lorentz Center, Leiden, The Netherlands – February 2020.
- Poster "Dispersion upscaling in highly heterogeneous aquifers: The prediction of tracer dispersion at the Macrodispersion Experiment (MADE) site", EGU General Assembly 2020 (online) May 2020.

Yannick De Decker

- Invited talk at the 2020 Digital Dynamics Days Europe (online) – 26 August 2020.

Anne De Wit

- Online invited seminar, University of Loughborough, UK – October 2020.
- Invited online CEPULB conference, Brussels, Belgium – November 2020.
- Online talk, 73rd Annual Meeting of the Division of Fluid Dynamics of the American Physical Society, Online meeting, USA – November 2020.

Mamta Jotkar

- Poster presentation on "Differential diffusivity effects in reactive convective dissolution"
  Workshop on 'Mixing in porous media', Lorentz Center, Leiden, The Netherlands – February 2020.
- "Differential diffusivity effects in reactive convective dissolution"
  Porous media tea time talks, Webinar series organized on YouTube – 6 October 2020.

Matvey Morozov

- "Nonlinear dynamics of chemically active microdrops grants: an insight into interfacial chemistry" in Annual Meeting of the COMPLEX Doctoral School, University of Namur, Namur, Belgium – February 2020.

Dimitra Spanoudaki

- "Oscillatory budding dynamics of a chemical garden within a co-flow of reactants"
  COST Chemobrionics conference, Czech Republic, Prague – 29 January - 1 February 2020.

Organized Conferences

- Yannick De Decker: Co-chair (with F. Dietrich and C. Siettos) of the workshop "Data-based analysis of complex dynamical systems", organized in the framework of the 2020 Digital Dynamics Days.

PUBLICATIONS

K. Wüthrich, B. Weckhuysen, L. Rongy and A. De Wit
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C. Thomas, S. Dehaeck, A. De Wit
Effect of precipitation mineralization reactions on convective dissolution of CO_2: an experimental study, Phys. Rev. Fluids 5, 113505 (2020).

M. Jotkar, L. Rongy, A. De Wit
Reactive convective dissolution with differential diffusivities: Nonlinear simulations of onset times and asymptotic fluxes, Phys. Rev. Fluids 5, 104502 (2020).

S.S.S. Cardoso, J.H.E. Cartwright, J. Cejkova, L. Cronin, A. De Wit, S. Giannerini, D. Horvath, A. Rodrigues, M.J. Russel, C.I. Sainz-Diaz, A. Toth
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M. Morozov
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A. Toth, G. Schuszter, N. P. Das, E. Lantos, D. Horvath, A. De Wit, F. Brau
Effects of radial injection and solution thickness on the dynamics of confined $A + B \rightarrow C$ chemical fronts, Phys. Chem. Chem. Phys. 22, 10278 (2020).

F. Brau, A. De Wit
Influence of rectilinear vs radial advection on the yield of $A + B \rightarrow C$ reaction fronts: A comparison, J. Chem. Phys. 152, 054716 (2020).

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DEPARTMENT OF

GROUP OF PROFESSOR GERT DESMET | VUB

RESEARCHERS

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Eeltink Sebastiaan *(full professor)*
Broeckhoven Ken *(assistant professor)*

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Van Geite Ward
Vankeerberghen Bert
Verloy Sandrien
Zhou Zhuoheng
Zhu Koudi

Demonstrating the benefits of order and confinement in chemical engineering

Rooted in chemical engineering, with a long standing specialization in microfluidics and analytical separation science (chromatography, DNA hybridization assays, microfluidic membrane separations…), the Desmet group is reputed for the development of novel analytical separation devices, as well as for its know-how on the modeling and understanding of flow effects in laminar flow systems. The group is also internationally reputed for its know-how on miniaturization and has over the last 20 years established an extensive set of microfluidics capabilities. Harvesting from this unique combination of know-how, our group was the first to show the dramatic acceleration in chromatographic separation that can be achieved by working at the nanoscale. Whereas conventional chromatographic separations are conducted with particles of a few micrometer and typically take minutes to be completed, moving to nanochannels with a height of only 100 nm enabled to do the same separation in less than 1/10th of a second. The group also realized an important breakthrough in the development of perfectly ordered separation beds. While flow heterogeneities are the enemy of separation processes, conventional separation beds are still filled with randomly packed spherical particles. Using advanced silicon micromachining (= a combination of the photolithography and Deep Reactive Ion Etching processes originally developed for the micro-electronics industry) allowed to develop microfluidic channels filled with perfectly ordered arrays of cylindrical micro-pillars. Because of the order, separation efficiencies are more than doubled compared to the standard technology. This work led to the creation of the spin-off company Pharma-Fluidics, currently employing about 20 FTE.

While continuing the work in these tracks, the Desmet group recently also entered two new research directions.

The first direction, funded through a recently attributed Methusalem grant, centers around the use of artificial intelligence (AI) in analytical separation sciences. This new research direction will focus on the generic research question asking whether it is possible to develop the software needed to make a "self-driving" chromatography instrument, one that would be capable of solving a given separation problem (=find chromatographic conditions that separate all components in the mixture) without human interference? A positive answer to this question would be a huge breakthrough, considering that finding the optimal chromatographic separation conditions typically requires wading through millions of different combinations with little more guidance than the one coming from the analyst's general knowledge. This optimization process therefore typically takes several weeks and constitutes a huge cost factor in pharmaceutical industry. In a first step towards the solution of this problem, we recently [1] compared three classes of evolutionary algorithms (genetic algorithms (GA), evolution strategies (ES) and covariance matrix adaptation evolution strategy (CMA-ES)) for their ability to enhance optimization searches in the method development spaces of 1D- and 2D-chromatography. After optimisation of the design parameters of the different algorithms, they were benchmarked against the performance of a plain grid search. It was found that all three classes significantly outperform the plain grid search, especially in terms of the number of search runs needed to achieve a given separation quality. As soon as more than 100 search runs are needed, the ES algorithm (Fig. 1) clearly outperforms the GA and CMA-ES algorithms, with the latter performing very well for short searches (<50 search runs) but being susceptible to convergence to local optima for longer searches.

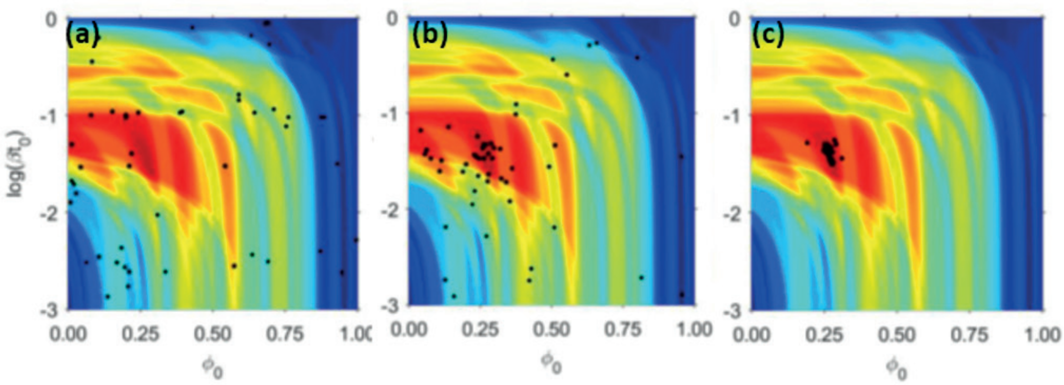

Figure 1. Graphical representation of how an Evolution Strategies search algorithm directs a random seed of search points (a) to focus around the optimal spot in the optimization space (black dots are trial runs). Panel (b) represents a situation half-way the search process.

It was also found that the performance of the ES and GA algorithms, as well as the grid search, follow a hyperbolic law in the large search run number limit, such that the convergence rate parameter of this hyperbolic function can be used to quantify the difference in required number of search runs. In the next step, this work is now continued by incorporating deep learning and instance-based machine learning strategies,

In a second new research track, we embarked on the development of novel fabrication methods to build ordered, hierarchical structures of functional micro- and nano-particles (3D printing of ceramic particles). Whereas this new research direction, funded by an ERC Advanced Grant, is inspired by the need for order in chromatographic separation beds, the pursued ability to make pre-designed 3D particle structures will for example also find important applications in photonics, as photonic band-gap materials or photonic crystals. A first technology to pursue such structures is Two-photon Polymerization Printing (2PP). This technology uses near-infrared (NIR) light to excite a photosensitive liquid material (resin) that upon light absorption locally solidifies through a polymerization process. Since two or more photons need to be simultaneously absorbed by the photoinitiator molecules present in the resin, and since the probability for such a multi-collision event is only high enough in the very inner core of a focused laser beam, the polymerization can be limited to regions with a size well below the wavelength of the incident light, thus allowing to print with voxel sizes as small as 300 nm and "write" three-dimensional bed structures with a nanometric precision (Fig. 2).

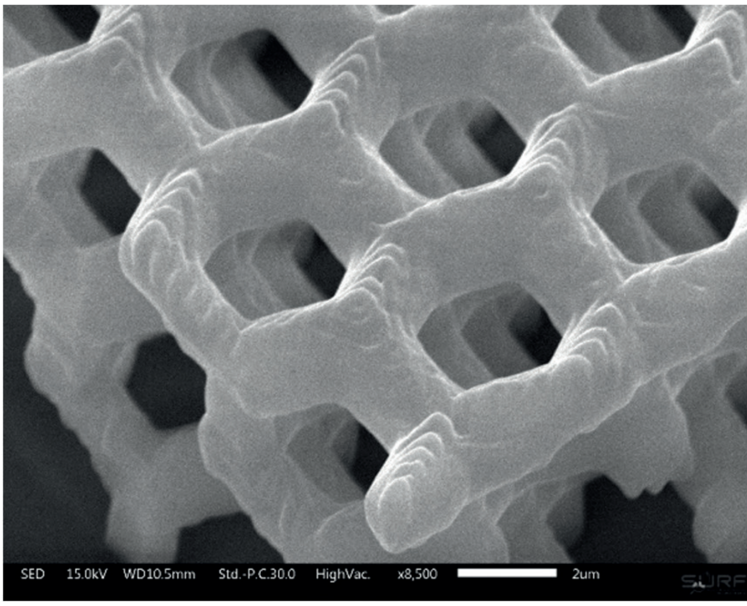

Figure 2. Three-dimensional polymer scaffold printed with nanometric precision using Two-photon Polymerization Printing

In the same track, we also started the development of a radically novel approach to the 3D-printing of (functionalized) micro- and nano-particles. Here we work on the development of an inventive layer-by-layer manufacturing strategy wherein each particle layer is first collected and arranged in the desired conformation using a vacuum-driven, micro-structured collection and deposition tray. This tray is arranged with an array of precisely positioned vacuum-suction holes capable of reversibly holding the particles. Subsequently, these layers can either be deposited in a pre-structured support grid or cemented to the previously deposited layers using a locally photocurable ceramic-based glue or cement. In the first part of this work, we developed a technology to ultra-rapidly assemble monolayers of spherical particles in any desired, pre-designed arrangement (Fig. 3), independently of their size or their material properties. The particles are fed to the assembly tray by aspiring them from a stable particle cloud generated using an electrostatic cell formed by two semi-conductor substrates separated by a few millimeters and subjected to 5 to 10 kV of DC Voltage.

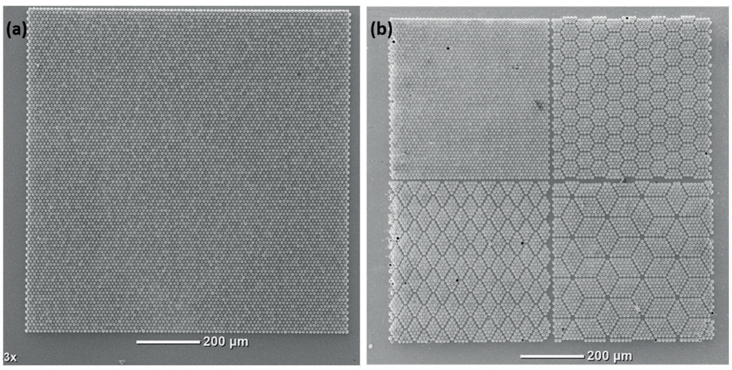

Figure 3. Large-areas ordered sphere packing with variable pattern obtained using the newly developed principle of vacuum-driven particle assembly technology.

During the course of the latter work, we also made the serendipitous discovery [2] of a new method for the directed particle segregation & self-assembly of silica particles by rubbing-induced tribo-electrification on surfaces patterned with fluorocarbon coated patches. We could explain the origin of this spontaneous segregation process (Fig.4) by the fact that silica particles are tribo-charged due to the rubbing process and therefore stick on the fluorocarbon coating, while they are repelled from the silicon regions in between the fluorocarbon patches because of the opposite charge. During the rubbing, a monolayer of particles is on the fluorocarbon surfaces, thus creating an ordered array of self-assembled particle collections. Using Kelvin Probe Force Microscopy (KPFM), we could show that the rubbing process induces electric charge on the FC coated surface and particles.

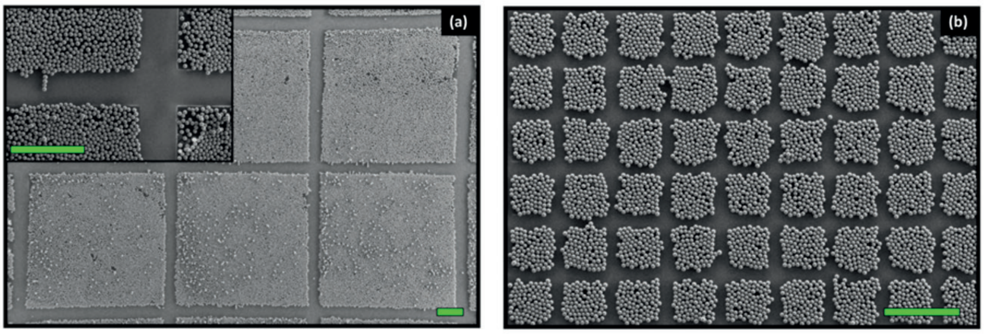

Figure 4. SEM images of the distribution of 5 micrometer silica particles after rubbing the particles over a borosilicate glass wafer patterned with an array of fluorocarbon squares. Scale bar in all images is 100 µm.

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**Bram Huygens is the 2019 winner of the Ilya Prigogine Prize VUB.*

ALGC RESEARCH

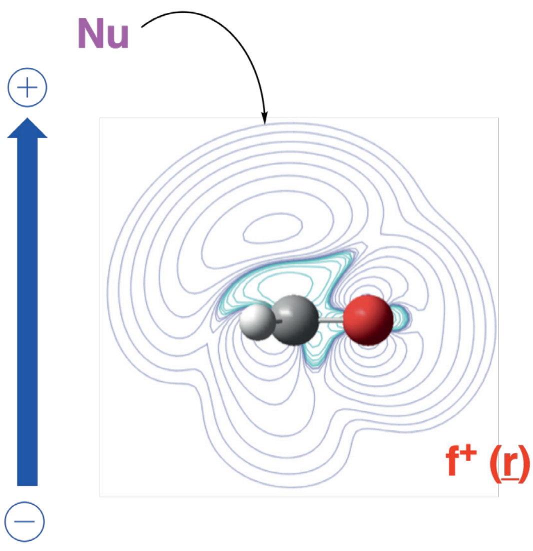
GROUP OF PROFESSORS FRANK DE PROFT, FREIJA DE VLEESCHOUWER

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 behavior in the molecules' real environment upon reactions, i.e. in most cases a solution, requiring ab initio Molecular Dynamics Simulations. Beyond and along these lines various applied quantum chemical studies are performed applying DFT based concepts and using DFT computational approximations on a variety of substrates most often carried out in direct interaction with experimentalists. Since 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, necessitating more and more a multiscale approach.

In this 2020 Report attention is paid to fundamental work in Conceptual DFT and Chemical Reactivity, Molecular Switches, Applied Quantum Chemistry (including Molecular Dynamics) 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

In recent years the Conceptual DFT part paid particular attention to extending the scope of Conceptual DFT by enlarging the number of variables in the energy functional permitting to scrutinize the response of molecular systems to a greater variety of perturbations. This endeavor, addressed in a recent Status paper on Conceptual DFT [2] allows to cope with the ever growing variability of external stimuli in creating innovating reaction conditions. In Tom Bettens' work the link was made with the vibrant field of Molecular Mechanochemistry [3] 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 [4-6]. Recently the influence of oriented external electric fields was incorporated in the context of the increasing interest in the mediation of chemical reactivity by these fields under the impetus of S. Shaik at the Hebrew University of Jerusalem [7]. A series of diatomics and small polyatomics were scrutinized concentrating on the shift of local reactivity descriptors such as the density and the Fukui function. The case of H_2CO thereby revealed the hitherto unexplored possibility to electric field induced enantioselectivity for a nucleophilic attack [8]. A parallel study with Prof. Teale from Nottingham on the influence of external magnetic



GROUP

FREDERIK TIELENS, MERCEDES ALONSO, AND PROFESSOR EMERITUS PAUL GEERLINGS | VUB

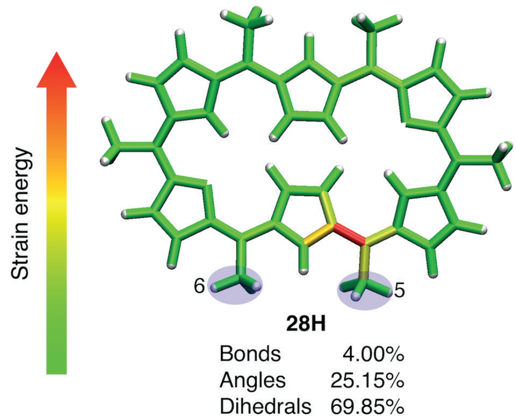
fields on global reactivity descriptors such as electronegativity, hardness and softness of atoms revealed the interesting complexity of the evolution of these properties as a function of increasing field strength due to the multiple switching of atomic electronic configuration through the alignment of the spin of the electrons with the field. [9]

As a step up to the presently investigated influence of external pressure the past and present of reactivity under confinement has been analyzed.[10]

Finally the work by Thijs Stuyver, during his postdoctoral stay with Prof. Shaik at the Hebrew University of Jerusalem, should be highlighted: they established a link between Valence Bond Theory , one of the two pillars of (molecular) wave function quantum theory (the other one being the well-known Molecular Orbital theory) and Conceptual DFT thereby completing the MO-VB-CDFT triangle [11]. The link between MO and CDFT indeed is well established for example via the Fukui function [1]. A study of the hardness- softness conundrum associated with protonation reactions constitutes an important step into a generalized VB-CDFT interpretation of chemical reactivity [12].

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 two topics received particular attention. 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-Möbius interconversions in extended π systems. This benchmark study against the most refined and performing wave function methods exploitable for systems of this size, of a variety of DFT approximations, among others pointed out the crucial influence of dispersion and the importance of including exact exchange. This will be of great value in further explorations of this research line [14].

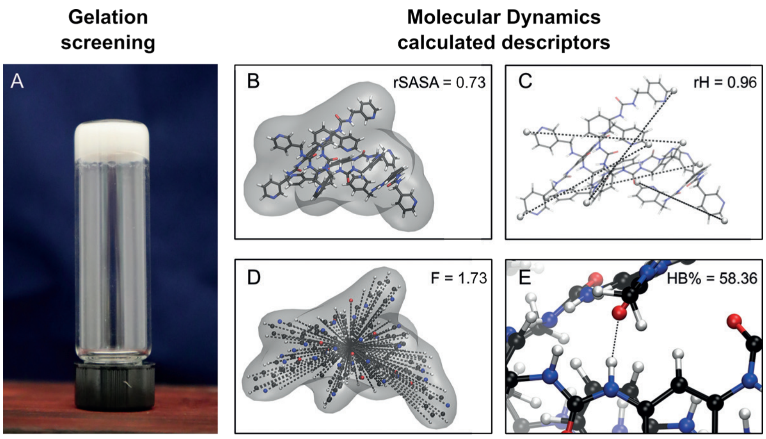


The second topic joined the mechanochemistry and switches research lines and was partly addressed during Tom Bettens' postdoctoral stay with Prof. Dreuw in Heidelberg. The take-home lesson is that mechanical forces are an effective stimulus to trigger the interconversion between Hückel and Möbius topologies in [28] hexaphyrin making these expanded porphyrines suitable to act as conformational mechanophores operating at mild (sub 1 nanometer) force conditions [6]. The figure shows the redistribution of the external mechanical energy for a pulling scenario at positions 5 and 6.

Applied Quantum Chemistry

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

In an ongoing collaboration [15] with the Laboratory for Molecular Design and Synthesis of the KULeuven (Wim De Borggraeve) Drs. Ruben Van Lommel, Frank De Proft 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 [16], for rationalizing the experimentally observed hydrogelation performance at stake in the rational design of low molecular weight gelators. As a natural sequel and to cope with trial-and-error approaches, a limited number of molecular dynamics-based descriptors were introduced to predict molecular gelation in both water and organic solvents. Their predictive ability was demonstrated via two separate machine learning techniques: the descriptors turn out to be able to accurately predict the gelation response of a set of urea-based gelators as a precipitate, a gel or a fully solubilized sample [17].



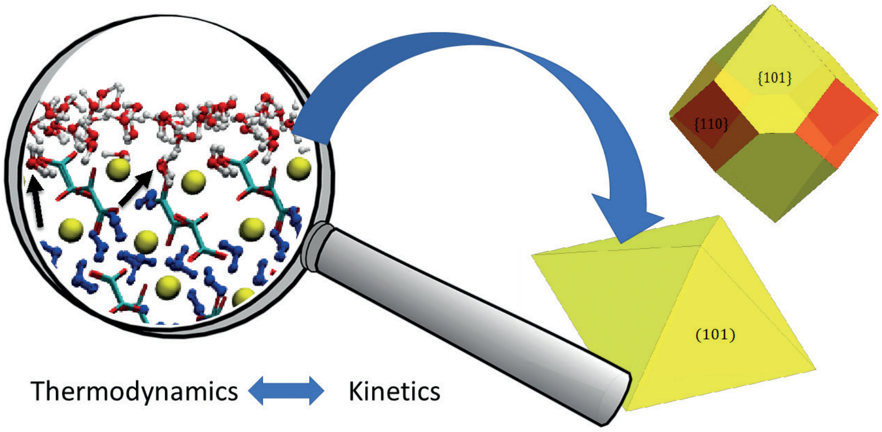
A second example is drawn from a collaboration with Prof. B. Weckhuysen (University of Utrecht) in a field of ever increasing importance in catalysis, namely single-atom catalysis [18] upon which the size of the active site of a catalytic metal cluster is reduced to its most extreme situation: a single atom dispersed on a support. In this context Weckhuysen recently explored, using a series of well-defined silica-supported Ni particles with varying size, how structure sensitivity influences the mechanism of the catalytic CO_2 reduction [19]. In a joint effort a Periodic DFT study was undertaken in the context of Xavier Deraet's Ph.D. thesis on the reactivity of single transition metal atoms on a hydroxylated amorphous silica surface.With an extension of Conceptual DFT to Periodic Systems the (coinciding) calculated and experimental results for adsorption strength and reactivity of group 8,9,10 transition-metals could be rationalized, promoting this ansatz to a valuable tool for the interpretation, and in a later stage prediction, of experimental catalytic data [20].

Materials Modelling

In this research line two examples are discussed sharing 1° their effort in linking morphological aspects of a crystalline structure and detailed molecular aspects upon interaction with an adsorbent and 2° their societal importance.

The first study, in collaboration with the Laboratoire Chimie de la Matière Condensée Sorbonne Université (Paris), aimed at predicting the morphology of calcium oxalate polyhydrate, whose societal importance shows up knowing that calcium oxalates have been widely studied in the literature in view of their role in the formation of stones in the kidney. In a Periodic DFT study the crystal morphology could be determined of the calcium oxalate monohydrate and dihydrate phases through minimization of the total crystal surface taking into account the effect of the physicochemical environment (in a first approximation pure water). Excellent agreement with the experimental Scanning Electron Microscope data [21] was obtained.
The figure shows this conceptual passage from a hydrated surface to the crystal morphology.

A second example is the adsorption of phosphate on hydrous ferric oxide. The thorough understanding of this adsorption mechanism is necessary to deal with environmental issues (the societal aspect) related to high phosphate concentrations in soils and open water.



Fe-(oxy) hydroxides, also called hydrous ferric oxides (HFO) are one of the minerals that has been shown to strongly inhibit the transport of phosphates through adsorption, due to their large, variable surface area and great surface reactivity. Also here DFT calculations were able to predict the most important HFO surface and, in a second step, its specific interactions with the phosphate ions considering monodentate and bidentate chemisorption. Just as in the previous study, but in a completely different context and for strongly different substrates, morphological aspects and interactions at the molecular level are linked [22].

The sections on Applied Quantum Chemistry and Materials Modelling illustrate that in its applied research ALGC is on the road to a multiscale approach allowing it, together with the more fundamental issues in the Conceptual DFT part, to address a broad spectrum of problems /issues in the Chemistry of today and tomorrow.

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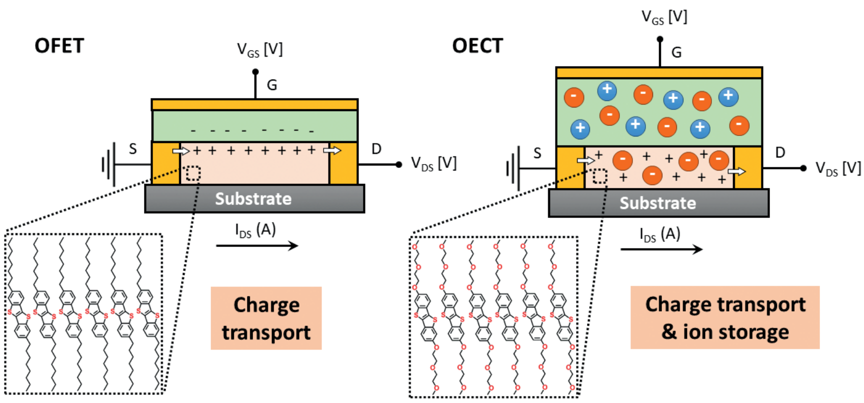
LABORATORY OF

GROUP OF PROFESSOR YVES GEERTS | ULB

Our major areas of research activity are related to the chemistry of functional molecular materials and their structural, thermal, optical, and electronic properties. Specifically, we work on:

π-Systems

We design, synthesize, and characterize π-systems for their use as semiconductors. Currently, we focus on thienoacenes that are among the best-performing materials for charge transport. Performances of semiconductors are essentially quantified by the charge carrier mobility, μ ($cm^2/V.s$). The state-of-the-art mobility values, measured in Organic Field Effect Transistors (OFETs), for organic semiconductors are on the order of 20 $cm^2/V.s$. Our goal is to beat the limit of 100 $cm^2/V.s$.(1) To this end, we try to design organic semiconductors that are resilient to thermal disorder by engineering their molecular structure and the shape of their frontier orbitals. A somewhat connected line of research deals with the design and synthesis of organic semiconductors able to transport electrons and holes and to store ions to use them in Organic Electro-chemical Transistors (OECTs). Such transistors that are able to process and to store information as synapses do, are key elements to create a new neuromorphic electronics.(2)



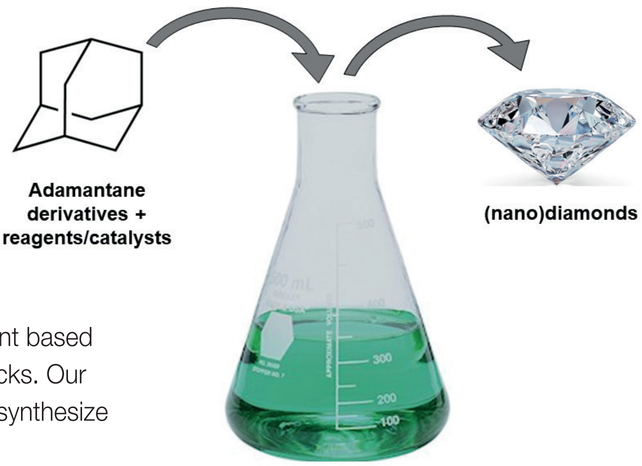
1 *"Molecular Semiconductors for Logic Operations: Dead-End or Bright Future?" Guillaume Schweicher, Guillaume Garbay, Rémy Jouclas, François Vibert, Félix Devaux, Yves H. Geerts,* Advanced Materials 2020, 32, 1905909.*

2 *"Liquid-Gated Organic Electronic Devices Based on High-Performance Solution-Processed Molecular Semiconductor", Michele Di Lauro, Marcello Berto, Martina Giordani, Simone Benaglia, Guillaume Schweicher, Dominique Vuillaume, Carlo A. Bortolotti, Yves H. Geerts, Fabio Biscarini, Advanced Electronic Materials 2017, 3, 1700159.*

POLYMER CHEMISTRY

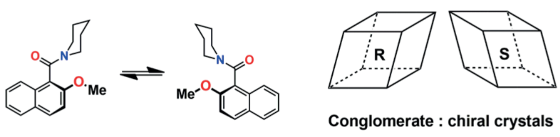
Nanodiamonds

Diamonds are known for their extraordinary properties and for their use in jewelry. Nanodiamonds, with size ranging from 2-5 nm, are of paramount interest for unprecedented applications in magnetic resonance imaging, quantum technologies, and biomedical applications. What makes them particularly attracting are their defects, such as nitrogen vacancies. Defects confer them a fluorescence that is particularly sensitive to temperature and magnetic fields. Unfortunately, nanodiamonds are difficult to synthesize in large amount because they require high-pressure and high temperature (HPHT) conditions.
We have recently elaborated a strategy to circumvent these inconvenient based on the chemistry of adamantane derivatives that serves as building blocks. Our ultimate goal would be to get rid of the use of pressure and be able to synthesize nanodiamonds near ambient conditions, like the synthesis of polymers.

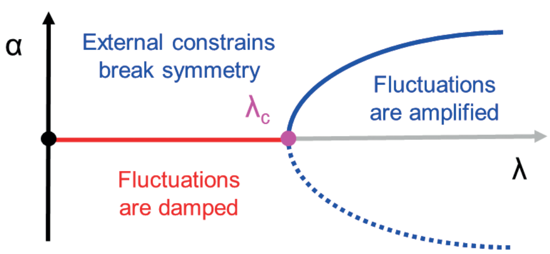


Crystals and thin films

Our research activities on crystals is threefold. First, we engineer the crystal structure of organic semiconductors with side groups such as alkyl side chains. By doing so, we modulate the electronic interactions between π-systems and tailor optical and electronic properties of organic semiconductors[3]. Second, we control the crystal growth of organic compounds by using specific non-equilibrium thermodynamic conditions.[4] On one hand, directional crystallization allows us to control the orientation/alignment of unit cells and to select specific polymorphs. Thin films are preferred because they facilitate the visualization of crystal growth by microscopy and the characterization of crystal structure by X-ray diffraction methods. In parallel to experimental studies, we rationalize our results from first principles. Third, we are interested in chiral symmetry breaking upon crystallization. Non-equilibrium conditions can lead to the deracemization of atropisomers. Currently, we study the use of external stimuli to tailor enantiomeric excess.[5]



$$d\alpha/dt = - A\,\alpha^3 + B\,(\lambda - \lambda_c)\,\alpha + \varepsilon^{1/2}\,\xi(t) + C\,g$$



3 "Bulky End-Capped [1]Benzothieno[3,2-b]benzothiophenes: Reaching High-Mobility Organic Semiconductors by Fine Tuning of the Crystalline Solid-State Order" Guillaume Schweicher, Vincent Lemaur, Claude Niebel, Christian Ruzié, Ying Diao, Osamu Goto, Wen-Ya Lee, Yeongin Kim, Jean-Baptiste Arlin, Jolanta Karpinska, Alan R. Kennedy, Sean R. Parkin, Yoann Olivier, Stefan C. B. Mannsfeld, Jérôme Cornil, Yves H. Geerts, Zhenan Bao, Advanced Materials 2015, 27, 3066-3072.

4 "Toward Single Crystal Thin Films of Terthiophene by Directional Crystallization Using a Thermal Gradient" Guillaume Schweicher, Nicolas Paquay, Claire Amato, Roland Resel, Markus Koini, Samuel Talvy, Vincent Lemaur, Jérôme Cornil, Yves Geerts and Gabin Gbabode, Crystal Growth Design 2011, 11, 3663-3672.

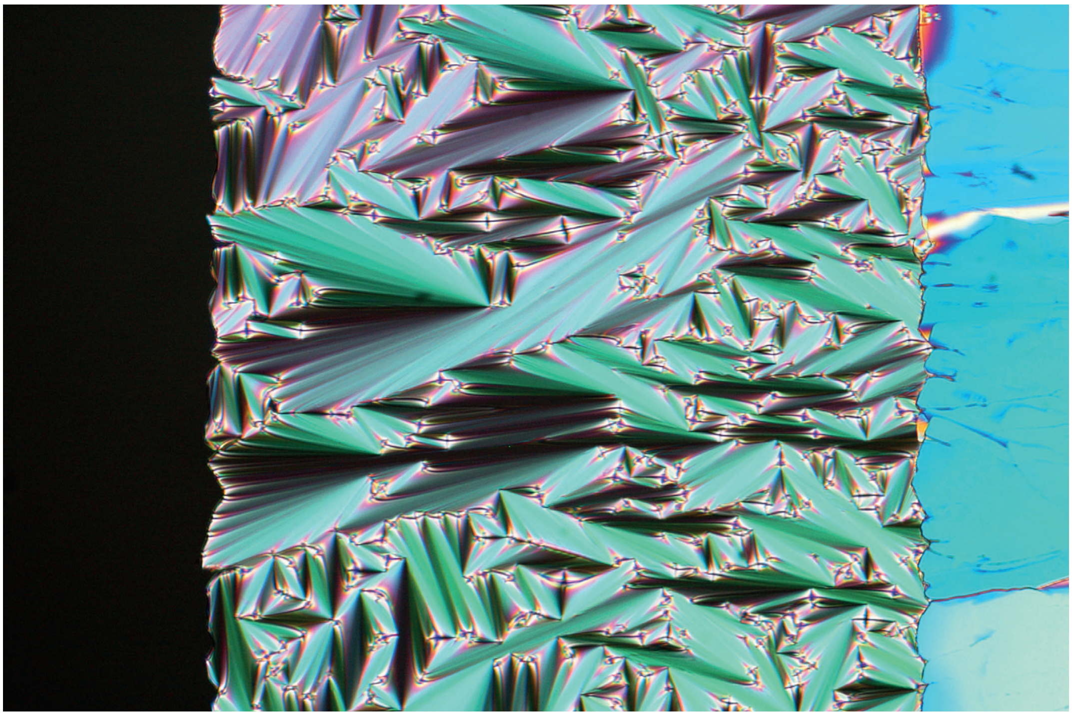
5 "Deracemization in a Complex Quaternary System with a Second-Order Asymmetric Transformation by Using Phase Diagram Studies", Ryusei Oketani, Francesco Marin, Paul Tinnemans, Marine Hoquante, Anne Laurent, Clément Brandel, Pascal Cardinael, Hugo Meekes, Elias Vlieg, Yves Geerts, Gérard Coquerel,* Chemistry European Journal 2019, 25, 13890-13898.

Dr. Guillaume Schweicher, who is a scientifically independent researcher in Geerts' group, develops an original research line on charge, spin, and heat transport in organic semiconductors.

He has recently highlighted multiple phenomena taking place in these materials. Due to their long carrier spin lifetimes (up to a millisecond), organic semiconductors could have an important impact on spintronics[6]. He has demonstrated that terminal alkyl chains suppress the spin injection and decrease the spin diffusion length for vertical spin transport in molecular semiconductors[7], opening the possibility of synthesizing tailor-made organic materials to optimize spin injection properties. It is only within the past few years that intermolecular motion has been recognized as the key factor and bottleneck limiting the charge transport properties of organic semiconductors.

Through a collaboration with Prof. Ruggiero (USA), Dr. D'Avino and Fratini (France), Dr. Schweicher has identified that only specific motions are detrimental to charge transport. These results set basis for the rational design of better organic semiconductors . The accurate resolution of the vibrational spectrum present in these materials also allows to understand their heat transport properties for the first time. He has initiated a collaborative network emphasizing the impact of molecular design on heat transport in molecular semiconductors through an accurate evaluation of their thermal conductivity: terminal alkyl chains strongly localize the lattice modes and reduce thermal conductivity. Combined with enhanced charge transport, it suggests that it might be possible to decouple electron and phonon transport in alkylated semiconductors which is of high interest for better thermoelectric[9] materials[10].

> There is a deep interconnection between art and sciences.



Interacting with artists brings so much in terms of discussions, ideas and concepts, to develop a more integrated approach to knowledge creation and sharing. Moreover, these interactions also provide brilliant ideas and connections for fundamental research.

Since October 2019, Dr. Schweicher started to interact with Ohme.[11] The most notable outcome from this collaboration, in 2020, is the realisation of the audiovisual performance: “Tales of Entropy”, staging the irresistible beauty and poetry of an organic compound changing its physical state in a thermal gradient, under polarized light.[12]

6 *Spintronics is a branch of electronics that takes full advantage of not only the charge, but also the spin of the charge carrier to transmit, process and store information. The spin (intrinsic angular momentum) carried by the electron is ± ½.*

7 *“Tuning Spin Current Injection at Ferromagnet/Non-Magnet Interfaces by Molecular Design”, A. Wittmann, G. Schweicher, K. Broch, J. Novak, V. Lami, D. Cornil, E. R. McNellis, O. Zadvorna, D. Venkateshvaran, K. Takimiya, Y. H. Geerts, J. Cornil, Y. Vaynzof, J. Sinova, S. Watanabe, H. Sirringhaus*, Physical Review Letters 2020, 124, 027204.*

8 *“Chasing the ‘killer’ phonon mode for the rational design of low disorder, high mobility molecular semiconductors”, G. Schweicher*, M. T. Ruggiero, G. D’Avino, D. J. Harkin, K. Broch, D. Venkateshvaran, G. Liu, A. Richard, C. Ruzié, J. Armstrong, A. R. Kennedy, K. Shankland, K. Takimiya, Y. H. Geerts, J. A. Zeitler, S. Fratini*, H. Sirringhaus*. Advanced Materials 2019, 31, 1902407.*

9 *Thermoelectricity is the mutual interaction between the flow of heat and the flow of charge.*

10 *“Thermal conductivity of benzothieno-benzothiophene derivatives at the nanoscale”. M. N. Gueye, A. Vercouter, R. Jouclas, D. Guérin, V. Lemaur, G. Schweicher *, S. Lenfant, A. Antidormi, Y. Geerts, C. Melis, J. Cornil*, D. Vuillaume*, Nanoscale **2021** DOI: 10.1039/D0NR08619C.*

11 *Ohme is a Belgian transdisciplinary and creative label, as an Associate Researcher on the establishment of art and sciences contents in accessible, educational and interactive formats. https://ohme.be*

12 *Performance premiered on 2020/10/23, Pilar, Brussels, https://ohme.be/studio/tales-of-entropy.*

YOANNA ALEXIOU | RESEARCH ASSISTANT | ULB

Thanks to a special support of the Solvay family, of the ULB and of the VUB, a major effort has been launched to make a complete inventory and a systematic filing of the archives of the Solvay Institutes. These are an invaluable testimony of our history, which we want to make public to a wide audience going beyond mere scientific circles. A particular effort is pursued towards the filing of the documents related to our chemistry activities, equally rich but less accessible.

A PhD student, Yoanna Alexiou, has been hired to achieve this task, which will constitute the backbone of her thesis. Below is a report of her activities and their context for 2020-2021.

Who Am I and what Am I Doing Here?[1]

I graduated with a master's degree in history in September 2015, specializing in the political and social history of science since the beginning of my master's degree in 2013. I first worked on the history of the *Institut interuniversitaire des sciences nucléaires* from 1947 to 1972 which formed the topic of my master's thesis. After my studies, I was hired at the ULB. Archives Centre from August 2015 to August 2018, first as a student, then as a research assistant and archivist in order to classify the Solvay Institutes records kept at the ULB. and to put online proceedings of the Solvay Conferences on Physics and Chemistry from 1911 to 1962.

Since September 2018, I am working with the Solvay Institutes and started a thesis under the supervision of Kenneth Bertrams, Anne De Wit and Marc Henneaux, while continuing to provide logistical and scientific support to the Archives Committee.

Besides my PhD research I continue to feed the exhibition part of the Solvay Science Project and participate in its dissemination and communication, contribute to the organization of the First Solvay Chemistry Council Centenary, offer scientific advice to the collaborators of the VUB and ULB who are working on the Solvay Science Project, support the submission of the Solvay Institutes' world's memory application to UNESCO, and establish the first contact with international archive centres.

Due to the pandemic, the last two points had to be postponed and at this time, I do not know when international travel will resume, allowing to access the different archive centres across the world. In the meantime, I have been focusing on my PhD and expect to submit the manuscript at the end of March or April 2022, and to defend later at the end of May or June 2022. These deadlines will allow me, first, to concentrate on translating the manuscript into English with the help of a professional translator and second, to work on the celebration of the First Solvay Chemistry Council Centenary until the end of the funding, that is late August 2022.

The aim is also to use the last months of funding to add new contents drawn from my thesis to the exhibition section of the Solvay Science Project website. An Instagram page has been created in this context in order to ensure visibility of the Solvay Science Project and sustain the writing period of the manuscript[2].

A History of the Solvay Councils on Chemistry and Solvay Institute: PhD Thesis

My thesis has the primary goal of serving the posterity of the Solvay Institutes and highlighting the often-forgotten history of the Solvay Conferences on Chemistry and the influence of the Solvay Institutes on the scientific world since its creation. This PhD thesis focuses on the social history of chemistry through the study of the Solvay International Institute for Chemistry. It will develop the history of *'the Construction of Knowledge and Reproduction of Scientifics (Chemists) through the study of the International Solvay Conferences of Chemistry between 1930 and 1987'* (working title; see more hereafter).

The history of the Solvay International Conferences on Chemistry is not an easy one to tackle. Very few research articles have been written on the topic, mostly since the Solvay International Conferences on Chemistry records remained unclassified until 2016[3]. There were therefore many potential approaches to develop a history of these Conferences in the frame of a PhD project.

After thoughtful consideration, I have chosen to focus on the period from 1930 to 1987 for several reasons.

Firstly, the 4th Solvay International Conference on Chemistry (1931) is the first one to address a unified theme, on this instance dedicated to inorganic chemistry. This reveals a turning point after ten years a large range of topics for the Solvay International Conferences on Chemistry, and the interference of physicists and modern physics.

1 See: https://www.linkedin.com/in/yoanna-a-b97ab268/

2 See: Rethinking_science_history on Instagram

3 VAN TIGGELEN Brigitte, «Les premiers Conseils de chimie Solvay (1922-1928). Entre ingérence et collaboration, les nouvelles relations de la physique et de la chimie», Chimie nouvelle, n° 17, janvier 1999, pp. 3015-3018; FAUQUE Danielle et VAN TIGGELEN Brigitte, "The Formation of the International Association of Chemical Societies" Chemistry International -- Newsmagazine for IUPAC, vol. 34, no. 1, 2012, pp. 8-11. https://doi.org/10.1515/ci.2012.34.1.8; LAMBERT Franklin, Le premier Conseil de Chimie Solvay 1913, ed. Archives de l'ULB, Bruxelles, 2013; LAMBERT Franklin et BERENDS Frits, Vous avez dit : sabbat de sorcières ? La singulière histoire des premiers Conseils Solvay, Paris, EDP Sciences, Collection : Sciences & Histoire / Sciences & History, octobre 2019; ALEXIOU Yoanna, «The Limits of Participation: Lucia de Brouckère, a Female Professor at the Solvay Conferences on Chemistry», Chimie nouvelle, n° 131, November 2019, pp. 4 à 9.

Secondly, whereas 1930 to 1987 is a period of stabilization for chemists, there is a definite evolution in the orientation of topics. Biochemistry appears to gain importance during the thirties from the 5th Solvay International Conference on Chemistry held in 1934 onwards. This part of chemistry becomes increasingly important over the years, leaving little room for inorganic or physical chemistry in the Solvay International Conferences on Chemistry throughout that chronological frame.

Thirdly, and finally, 1987 appears as a pivotal date, as the organization of a particular Solvay Conference meeting in the United States, bringing together physicists and chemists around the question of Surface Science occurred that year. During this event, Solvay Conferences adopt a different format, moving away from the tradition set up by Hendrik Lorentz in 1911, with a symposium common to the two branches – physics and chemistry – represented within the Solvay Institute.

In addition to these issues of disciplinary history, the organization of the Solvay Institutes– both the administrative Commission and the Scientific Committee – underwent constant changes and the members sitting on the various committees shaped its operations. The model as conceived in 1911 and 1913 evolved subtly through the series of Solvay Conferences until the unification of the Solvay International Institute for Chemistry and the Solvay International Institute for Physics into a single body in 1970: The Solvay International Institutes for Physics and Chemistry founded by Ernest Solvay, also known as Solvay Institutes, as it exists today.

Although it retains separate Scientific Committees for each of the fields of science it represents, the administrative Commission is shared, and a General Assembly is created. The years between 1957 and 1987 witness numerous attempts to adapt the model proposed by Lorentz in 1911 under the chairmanship of Ilya Prigogine, with the active support by Jacques Solvay. This was a period of reorganization and adaptation for the Solvay Institutes as international conferences multiplied all over the world, mainly in United Kingdom and the United States, the Western bastions of chemistry and physics research after the Second World War.

As collaborators and good friends in their private lives, Ilya Prigogine and Jacques Solvay operated to keep the Solvay Institutes at the forefront of fundamental research meetings for more than thirty years. They adapted Lorentz's model to ensure Solvay Conferences would remain a reference, willy-nilly, for international scientific meetings related to chemistry and physics through several periods of history that proved to be complicated for international scientific collaboration, such as the Great Depression, the Second World War and the Cold War.

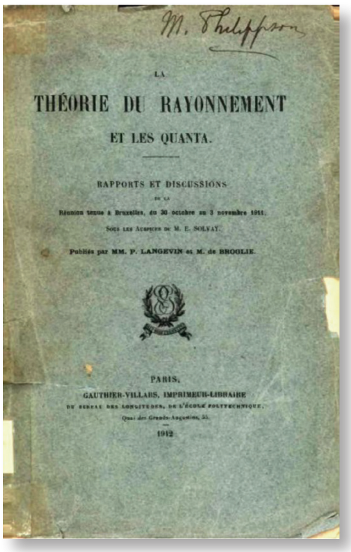
My approach is more social than political, since I am mainly interested into chemists who made the Solvay Institutes what it was–and has become–: the organization responsible for the world's most prestigious scientific conferences. For instance, many of the participants are Nobel Prize winners or well-established researchers on the way to receive this prestigious award. The question, in the end, is not so much to tell the story of the Solvay Institutes and the Solvay International Conference(s) on Chemistry as to understand why participating in these Conferences is considered as a significant honour, and to analyse how the members of the Institutes' Commissions work to maintain Solvay Conferences on Chemistry's prestige on the international scientific stage. The regular work of these chemists and physicists within the Solvay Institutes ensures that it still exists, more than a hundred years after its creation, and that it is still considered, within the relevant scientific community, as a prestigious meeting place, whereas other institutions, which had a similar purpose, have not managed to endure or to keep the aura they enjoyed at their beginnings[4].

4 *Yoanna Alexiou,* 'The Construction of Knowledge and Reproduction of Scientifics (Chemists) through the study of the International Solvay Conferences of Chemistry between 1930 and 1987'*, 2022 (working title).*

The Solvay Science Project

For dozens of years, only the Solvay Institute of Physics' records from 1910 to 1958 had been filed. Between 2016 and 2019, records of the Solvay International Institute for Physics from 1958 to 2003 and the Solvay International Institute for Chemistry from 1913 to 2003 were made accessible to research at last. This rediscovered heritage is the starting point for a wider valorization project which is still under construction: the Solvay Science Project[5].

The digitization of twenty-four Conferences' proceedings and several records has been achieved, and these documents were put online in a database. This action is fully aligned with the iterative principle of expanding and sharing scientific knowledge at the core for the Solvay Conferences from 1911 onwards the present day throughout the scientific and academic world[6].



Cover page of the Proceedings of the First Solvay Physics Council, 'La théorie du rayonnement et les quanta : rapports et discussions de la réunion tenue à Bruxelles du 30 octobre au 3 novembre 1911' under the auspices of M. E. Solvay, published by MM. P. Langevin and M. de Broglie, 1912 (Archives de l'Université libre de Bruxelles, also available online).

However, the Solvay Institutes wanted to go beyond this transmission of knowledge within the inner circle of researchers. After more than a hundred years of existence, they wanted to reach out to the general public, especially young people, to inspire secondary school students and interest them into physical and chemical sciences. The aim was no longer to promote archives and heritage with a view to disseminating them within the scientific community, but to popularize this heritage, to place it in its historical, social and political context and to present it as an educational tool namely, in our case, the "virtual exhibition"[7].

In 2016, the software that seemed to be the most appropriate to meet the Solvay Institutes' requirements was the 'OMEKA' software[8]. This open-source platform created by the Centre for History and New Media (CHNM) of George Mason University (Virginia, USA) has been used by many libraries and universities. It seemed therefore possible to combine knowledge dissemination for the scientific world and its popularization for the general public, within the same website.

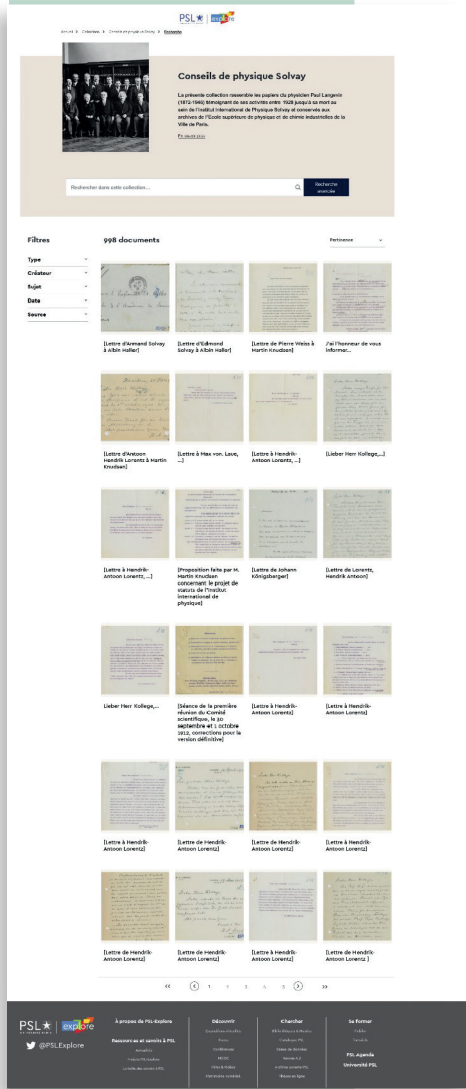
From the wealth of documents (all the proceedings and 550 records selected to appear in the 'database' section), it was then a matter of choosing about a hundred documents, pictures and illustrations to showcase them in an 'exhibition' section. The latter follows a linear narrative thread but can also be consulted in the form of 'mapping' – a non-linear, 'networked' navigation made possible through tags and hyperlinks.

As part of the range of techniques for popularizing knowledge, a series of interviews and lectures with members of the Administrative Commission and the Scientific Committees of the Institutes have also been put online[9].

Another way of popularizing this history was the creation of a 7-minute interactive video clip, produced by Kenneth Bertrams and Daniel Cattier, to serve as an introduction to the virtual exhibition[10]. The video looks back at the history of the first Solvay Conference on Physics in 1911 and the break in international scientific relations caused by the First World War, which changed the way in which chemistry and physics developed after 1918.

Supported and produced by ULB and VUB, the site is available in French, English and Dutch. Due to the international character of the Solvay Institutes, the English version is the most visited one since the exhibition went online on the 07th of May 2018.

Overview of the 998 references added to the S.S.P. website and available for consultation on the P.S.L. website, P.S.L.-Explore



The Solvay Science Project: a work in progress

The next challenge is to highlight the international dimension of the Solvay Institutes by connecting all the archives kept outside Brussels through the website. This new step is only possible with the support of international collaborators and institutions where historical material on the Solvay Conferences is kept, such as the *École Supérieure de Physique et de Chimie industrielle de Paris* (ESPCI) and *Paris Sciences et Lettres* (PSL), for example. The latter already have a large "Solvay corpus" digitized and accessible on their own digital library, *PSL-Explore*[11].

In October 2020, they have officially joined the Solvay Science Project. In concrete terms, this collaboration takes the form of an addition of more than 900 references linked to the history of the Solvay Council on Physics and the Solvay Institute for Physics between 1910 and 1950.

5 *See: http://www.thesolvayscienceproject.be/exhibits/show/the-solvay-science-project*

6 *See: http://www.thesolvayscienceproject.be/collections/browse*

7 *See: http://www.thesolvayscienceproject.be/exhibits/show/the-solvay-science-project?lang=en*

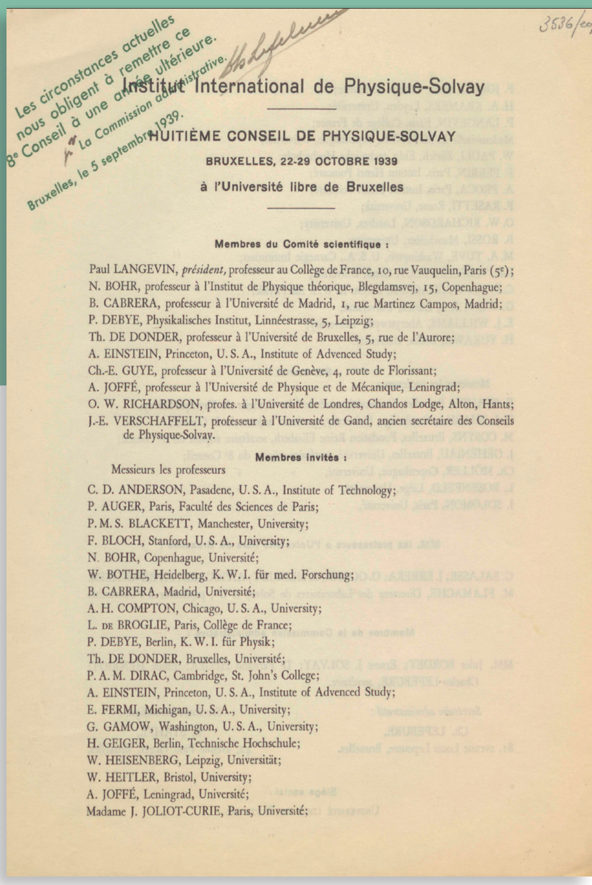
8 *See: https://omeka.org/*

9 *See: http://www.thesolvayscienceproject.be/exhibits/show/the-solvay-science-project/th--me-8*

10 *See: http://www.thesolvayscienceproject.be/exhibits/show/the-solvay-science-project/th--me-1/le-conseil-de-physique---bruxe*

11 *See: https://bibnum.explore.P.S.L..eu/s/P.S.L./ark:/18469/1nt9*

Since the Solvay Science Project went online in May 2018, new archives kept at ULB have also been digitized and added to the database in 2019 and in 2020. These records concern the Solvay Conferences on Chemistry of 1934, 1947 and 1953 and the 8th Solvay Conference on Physics cancelled twice, in 1936 and 1938, and which finally took place after the Second World War in 1948 on a subject different than nuclear fission.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Les circonstances actuelles nous obligent à remettre ce 8e Conseil à une année ultérieure.
La Commission administrative.
Bruxelles, le 5 septembre 1939.

Institut International de Physique-Solvay

HUITIÈME CONSEIL DE PHYSIQUE-SOLVAY

BRUXELLES, 22-29 OCTOBRE 1939

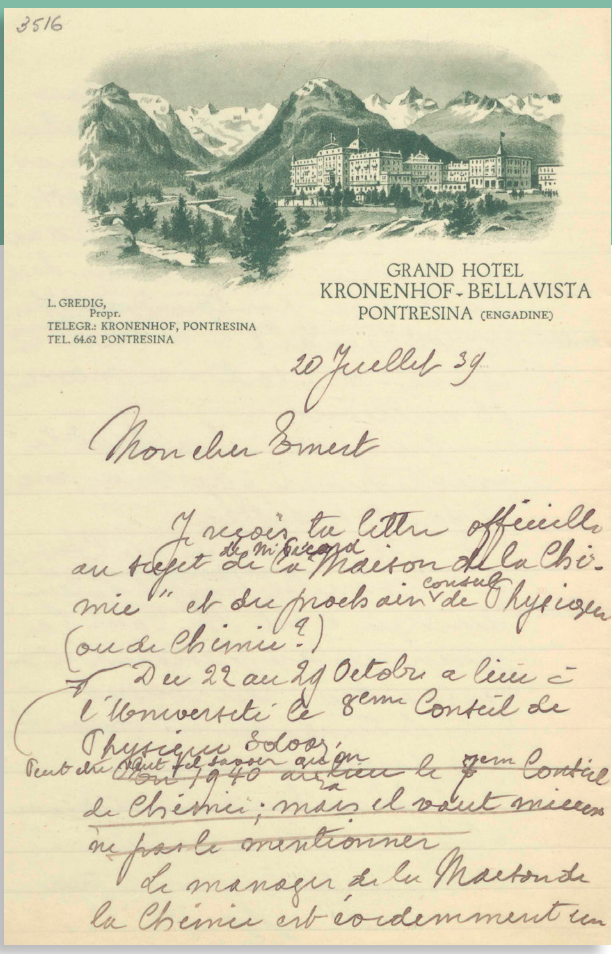
à l'Université libre de Bruxelles

Membres du Comité scientifique :

Paul LANGEVIN, *président*, professeur au Collège de France, 10, rue Vauquelin, Paris (5e);
N. BOHR, professeur à l'Institut de Physique théorique, Blegdamsvej, 15, Copenhague;
B. CABRERA, professeur à l'Université de Madrid, 1, rue Martinez Campos, Madrid;
P. DEBYE, Physikalisches Institut, Linnéestrasse, 5, Leipzig;
Th. DE DONDER, professeur à l'Université de Bruxelles, 5, rue de l'Aurore;
A. EINSTEIN, Princeton, U. S. A., Institute of Advenced Study;
Ch.-E. GUYE, professeur à l'Université de Genève, 4, route de Florissant;
A. JOFFÉ, professeur à l'Université de Physique et de Mécanique, Leningrad;
O. W. RICHARDSON, profes. à l'Université de Londres, Chandos Lodge, Alton, Hants;
J.-E. VERSCHAFFELT, professeur à l'Université de Gand, ancien secrétaire des Conseils de Physique-Solvay.

Membres invités :

Messieurs les professeurs
C. D. ANDERSON, Pasadene, U. S. A., Institute of Technology;
P. AUGER, Paris, Faculté des Sciences de Paris;
P. M. S. BLACKETT, Manchester, University;
F. BLOCH, Stanford, U. S. A., University;
N. BOHR, Copenhague, Université;
W. BOTHE, Heidelberg, K. W. I. für med. Forschung;
B. CABRERA, Madrid, Université;
A. H. COMPTON, Chicago, U. S. A., University;
L. de BROGLIE, Paris, Collège de France;
P. DEBYE, Berlin, K. W. I. für Physik;
Th. DE DONDER, Bruxelles, Université;
P. A. M. DIRAC, Cambridge, St. John's College;
A. EINSTEIN, Princeton, U. S. A., Institute of Advenced Study;
E. FERMI, Michigan, U. S. A., University;
G. GAMOW, Washington, U. S. A., University;
H. GEIGER, Berlin, Technische Hochschule;
W. HEISENBERG, Leipzig, Universität;
W. HEITLER, Bristol, University;
A. JOFFÉ, Leningrad, Université;
Madame J. JOLIOT-CURIE, Paris, Université;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GRAND HOTEL
KRONENHOF-BELLAVISTA
PONTRESINA (ENGADINE)

L. GREDIG,
Propr.
TELEGR.: KRONENHOF, PONTRESINA
TEL. 64.62 PONTRESINA

20 Juillet 39

Mon cher Ernest

Je reçois ta lettre officielle au sujet de M. Girard de la "Maison de la Chimie" et du prochain consul de Physique (ou de Chimie ?)
Du 22 au 29 Octobre a lieu à l'Université le 8ème Conseil de Physique Solvay. [illegible]

To support ULB work teams, Sarah Bourazma, a student in medieval history and archival studies, was hired in February 2020 with the financial support of the *Prix Wernaers (Fonds National de la Rercherche Scientifique)* obtained in 2018 by Anne De Wit and Yoanna Alexiou. Bourazma's tasks consist of focusing on developing and put online Solvay Institute's new acquisitions for the Solvay Science Project – in accordance with the agreement signed between ULB, Solvay Institutes, ESPCI and PSL – but also to work on the new digitization of the Solvay Institutes archives kept at ULB in collaboration with the ULB Libraries and the archive committee for Solvay Institutes.

In parallel, since January 2021, Marina Solvay has established contact with the Marie Curie Museum in Warsaw to integrate them in the Solvay Science Project.

In February 2021, an Instagram page dedicated to my research on the Solvay Conferences on Chemistry and Solvay Institutes was created in order to continue to spread this history.

New contents are also under construction on the exhibition part of the Solvay Science Project French version[13].

13 See: http://www.thesolvayscienceproject.be/news

Conferences and symposia (given and to come) in the framework of the Solvay Science Project and Solvay Conferences on Chemistry promotion

- *July 2021 (Upcoming) – "Nucleoproteins" 1959 Solvay Conference on Chemistry: a scientific network and (bio) chemistry state's case study in the late'50s 'contributed paper to the Symposium organized by the Commission on the History of Chemistry and Molecular Sciences, in the frame of the 26th International Congress of History of Science and Technology, Prague (online).*
- *August 2019 – "Solvay Conferences for Chemistry and International Union of Pure and Applied Chemistry conferences in the 1920s: fundamental, applied and industrial chemists competing or working together?" invited talk at the panel "IUPAC and the other international scientific organization: competition or synergy?" in the frame of the 12th International Conference on the History of Chemistry – Maastricht, The Netherlands.*
- *13-14 August 2018 – "The Solvay Science Project: a brief history of a long-term interdisciplinary team working process", Conference in the frame of the Second Workshop on Scientific Archives in Washington, USA organised by CAST (Committee on the Archives of Science and Technology of the International Council on Archives/Section on University and Research Institution Archives).*
- *19 June 2018 – "The Solvay Science Project: a brief history of a long-term interdisciplinary team working process", Conference in the frame of the day of "A cultural heritage to be revealed: Heritage of chemistry", Groupe d'histoire de la chimie, Société Française de Chimie, Paris, France.*
- *22 May 2018 – "Solvay et la République internationale des Sciences: courts métrages commentés", dans le cadre du cycle de conférences "La Science à la lumière de son Histoire", Centre national d'histoire des sciences.*
- *September 2017 – "Lucia de Brouckère", Conference in the frame of the 11th International Conference on the History of Chemistry, Trondheim, Norway.*
- *20 March 2017 – ULB, Printemps des Sciences. Jean-Marie Solvay, Pierre Marage, Yoanna Alexiou, "Les réseaux scientifiques de la révolution quantique (1910-1937). Bruxelles, capitale internationale de la science et les Premiers Conseils Internationaux de Physique et de Chimie".*
- *23 March 2017 – ULB, Printemps des Sciences. Brigitte Van Tiggelen, Anne De Wit, Yoanna Alexiou, "Femmes et Sciences : quelle contribution au développement de la chimie et de la physique à Bruxelles ? Marie Curie, Lisa Meitner et Lucia de Brouckère (1910-1960)".*

05

APPENDIX

Automne 1911, Bruxelles. Une réunion mythique, un casting phénoménal : Albert Einstein, Marie Curie, Henri Poincaré, Max Planck, Paul Langevin, Maurice de Broglie et d'autres réinventent la science lors du conseil Solvay, dans le plus beau palace de la ville

« JE PRENDS UN BAIN TOUS LES MATINS. NOUS SOMMES LES INVITÉS DE M. SOLVAY, Y COMPRIS AUX REPAS.

Mais il sait que, pour cela, la théorie des quanta, alors très controversée, doit être validée au plus haut niveau. » Pour que son propre génie soit reconnu, il faut que les idées de Planck et d'Einstein le soient préalablement !

Organiser une conférence chez lui, dans son Institut de Berlin, pour faire accepter la théorie d'un autre Allemand et conforter ainsi ses propres travaux ? « *Nernst comprend bien que ce serait cousu de fil blanc*, dit Franklin Lambert. *Il sait qu'il lui faut une autre solution.* » Il

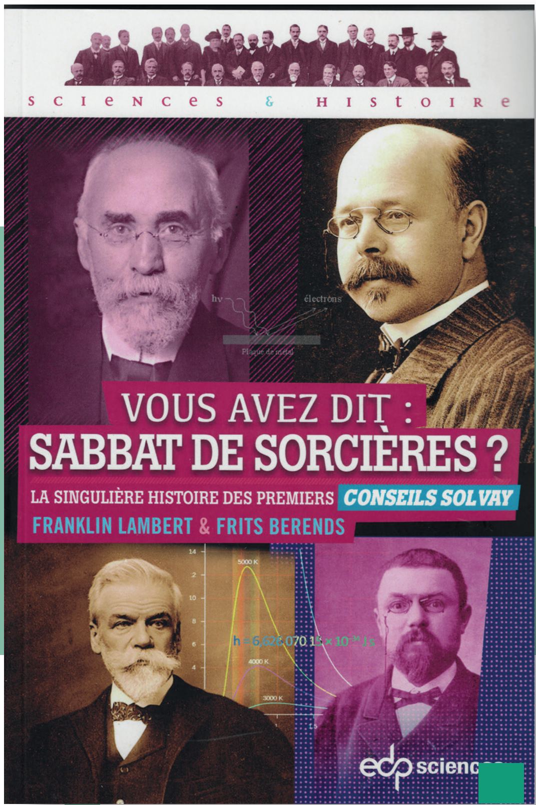
tière et l'énergie, qu'il formulera en 1887, dix-huit ans avant qu'un certain Albert Einstein ne l'établisse, l'incarnant dans l'équation la plus célèbre de la physique ($E = mc^2$). Epris de connaissance, profondément désireux de faire avancer le savoir, il fonde un institut de physiologie à l'Université libre de Bruxelles en 1894, puis une école de commerce, un institut de sociologie...

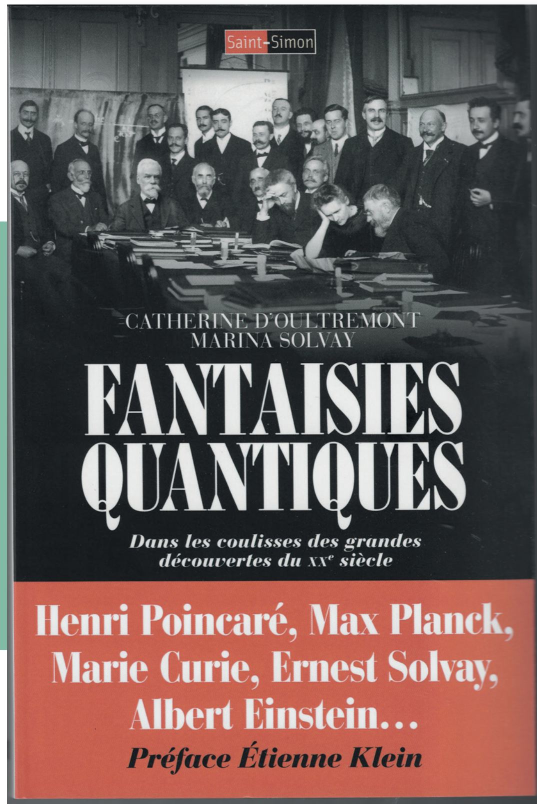
TERRAIN NEUTRE

vants, les laisser confronter leurs idées, et se mettre d'accord sur la réalité des fameux quanta. Mais il amende la liste des invités préparée par Nernst et ajoute plusieurs Français qui n'étaient pas prévus au programme : sur l'insistance du mécène, Marie Curie, Marcel Brillouin et surtout Henri Poincaré seront de la partie. Ce choix sera déterminant.

Quant au lieu, il s'impose de lui-même. Solvay est belge, la réunion se tiendra en Belgique, terrain neutre, carrefour de l'Europe

BOOKS &





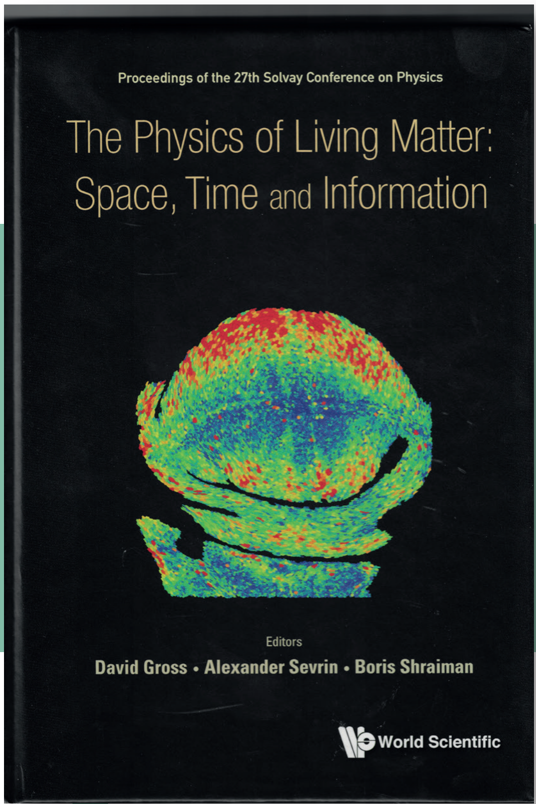
"Vous avez dit sabbat de sorcières?
La singulière histoire des premiers Conseils Solvay".

Auteurs: Franklin Lambert & Frits Berends
Editeur: EDP Sciences, Paris
ISBN: (papier):978-2-7598-2371-0
ISBN: (ebook): 978-2-7598-2404-5

"Fantaisies Quantiques"

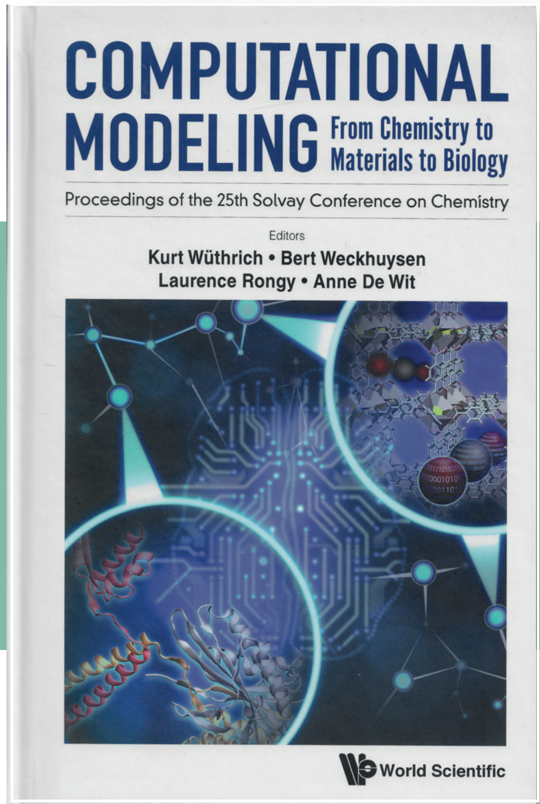
Auteurs: Catherine d'Oultremont & Marina Solvay
Editeur: Saint-Simon
ISBN: 9782374350219

PROCEEDINGS



"The Physics of Living Matter:
Space, Time and Information"

Editors: David Gross, Alexander Sevrin & Boris Shraiman
Publisher: World Scientific
ISBN: 978-981-3239-24-1



"Computational Modeling
From Chemistry to Materials to Biology"

Editors: Kurt Wüthrich, Bert Weckhuysen, Laurence Rongy
& Anne De Wit
Publisher: World Scientific
ISBN: 978-981-122-820-9

Le cinquième enfant d'Ernest Solvay n'a pas pris une ride

Marina Solvay, l'arrière-arrière-petite-fille d'Ernest Solvay, fondateur du groupe industriel du même nom, a plongé dans l'histoire des Conseils Solvay. Une saga scientifico-familiale intitulée «Fantaisies quantiques», qu'elle cosigne avec Catherine d'Oultremont.

Par Christian Du Brulle

«Prenez soin de mon cinquième enfant!» Peu avant son décès, en 1922, le chimiste et industriel belge Ernest Solvay lançait cette requête à ses héritiers. Son cinquième enfant? L'homme d'affaires ne dévoilait pas là l'existence d'un enfant issu d'une relation extraconjugale. Il parlait de la science, des Conseils de physique et de chimie Solvay gérés chacun par un Institut, qu'il avait créés avec l'aide précieuse du

qui avait fait fortune grâce à l'invention d'un procédé de fabrication industrielle de la soude était aussi un grand amateur de sciences. Il disposait de son laboratoire personnel à Bruxelles et menait ses propres recherches.

Quand en 1910, le physicien allemand Walther Nernst lui proposa d'organiser un vaste concile international consacré à un sujet naissant qui mobilisait la communauté scientifique de l'époque, la théorie des quantas, Solvay accepta. Les nouvelles théories physiques portées par Max Planck

Solvay venait de métamorphoser Bruxelles en un haut lieu

de physique (il n'aimait pas le mot «concile») s'ouvrait à Bruxelles. Du grand mécénat, mais également une manière pour Ernest Solvay de présenter à un ensemble de savants sa propre théorie et de trouver une réponse aux questions qu'il se posait.

C'est cette saga, qui dure depuis quasi 110 ans (le prochain Conseil de physique Solvay est programmé pour 2021), que Marina Solvay, l'arrière-arrière-petite-fille d'Ernest Solvay, nous détaille dans un livre

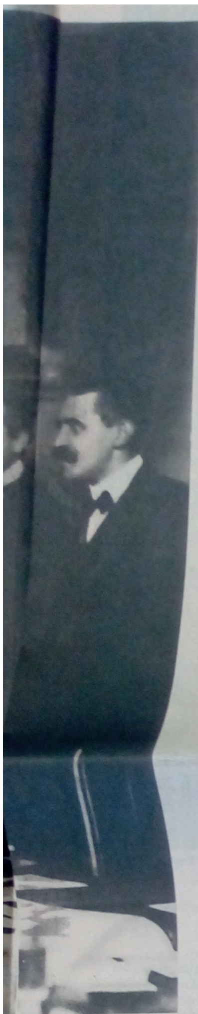
réunions scientifiques jusqu'en 1958. Le livre se lit comme un roman. L'ouvrage distille de multiples détails sur la vie de l'industriel, y compris certaines anecdotes familiales. Il livre aussi de nombreux dét[ails] biographiques, parfois romancés, des savants qui ont «fait» les Conseils Solvay. [La] célèbre liaison entre Marie Curie et le physicien Paul Langevin, qui aimait recevoir dans sa garçonnière, n'est pas éludée. Les tensions entre Albert Einstein [et] sa première épouse, Mileva Marić, [...]

L'ECHO | 23 May 2020

SCIENCE

Marina Solvay

«Les Allemands n'ont pu être invités qu'à partir de 1927, avec la permission du Roi»



Les participants au premier Conseil Solvay, en 1911, réunis autour d'une grande table, à l'hôtel Métropole. Ernest Solvay n'était pas présent au moment où la photo a été prise, il a été rajouté par montage (3e assis en partant de la gauche). On remarque la présence d'Albert Einstein (2e debout en partant de la droite) et de Marie Curie (assise), seule femme participante. © DOC

«Vous verrez, quand cela sera possible, que le fond de mes recherches et celui des vôtres sont communs, en ce sens qu'ils se rapportent l'un et l'autre à la constitution de la matière, de l'espace et de l'énergie», rapportent les deux auteures. «La méthode que j'ai suivie a été déductive, expliquait-il. Je suis parti initialement d'une conception générale préalable qui pouvait, à mon sens, satisfaire l'esprit philosophique constructif le plus scrupuleux [...]. Je me suis imposé de restituer l'Univers actif avec le mécanisme intime, déterminé, des éléments primordiaux. [...] Vous verrez donc qu'au fond, d'après ce qui précède, cette étude est plutôt de l'ordre de la philosophie physique que de la physique courante. J'émets depuis plus de quarante ans l'opinion que, pour la reconstitution mentale essentielle de l'Univers actif à laquelle nous travaillons tous avec conviction, le dernier mot de suprême éclairement devra être dit par le philosophe.»

«Ernest Solvay avait choisi de ne pas participer aux Conseils, ne se considérant pas comme assez compétent.»

MARINA SOLVAY
ARRIÈRE-ARRIÈRE-PETITE-FILLE
D'ERNEST SOLVAY

choses étaient devenues moins faciles entre les époux», relatent Marina Solvay et Catherine d'Oultremont. «Albert s'irritait quand elle se mêlait de ses recherches.»

Ce que le livre ne détaille pas, par contre, c'est l'anecdote liée à la photo historique qui illustre pourtant sa couverture. Le cliché en noir et blanc, mondialement connu, montre les participants au premier Conseil Solvay réunis autour d'une grande table, à l'hôtel Métropole, en présence d'Ernest Solvay. Or, l'industriel n'était pas présent le jour de la photo. Il a été ajouté par la suite. Il s'agit donc d'un montage. «Je n'en parle pas dans mon livre», concède Marina Solvay. «Cette anecdote a le don d'horripiler mon frère, et avant lui notre père. Mais elle est véridique. Le jour où la photo a été prise, Ernest Solvay ne pouvait être présent au Métropole. Il était par contre bien présent à l'ouverture du Conseil, pour y accueillir les participants et y prononcer plusieurs discours. Il avait choisi de ne pas participer aux Conseils, ne se considérant pas comme assez compétent».

Une théorie toute personnelle...

C'est à cette occasion, et après avoir remercié les savants qui avaient répondu positivement à son invitation, qu'Ernest Solvay leur glissa un mot sur une idée toute personnelle, sa propre théorie «gravito-matérialitique». «Il ne l'a pas réellement présentée», précise Marina Solvay. «Il a distribué à chaque participant un résumé de sa théorie en l'introduisant oralement par la citation ci-dessous et en espérant qu'après le Conseil, il en aurait des échos».

...qui ne sera pas débattue

La théorie d'Ernest Solvay, qu'il murissait depuis 1877, n'y fut cependant pas débattue. Elle portait sur la matière et ses aspects énergétiques, en relation avec la gravitation. «M. Solvay a été préoccupé de tout temps par le problème de la constitution de la matière. Sa gravito-matérialitique implique une variation d'énergie non d'une façon continue, mais par sauts et degrés», rapportait en 1911 un de ses collaborateurs, Édouard Herzen.

L'industriel proposa cependant à la fin du premier Conseil de physique d'organiser un second Conseil deux ans plus tard. Une proposition qui fut accueillie avec enthousiasme. L'espoir d'Ernest Solvay était d'y voir sa théorie discutée par les participants. Mais ce ne fut pas plus le cas que lors du Conseil de 1911. Néanmoins, les Conseils étaient lancés.

Le premier Conseil de physique Solvay venait de démarrer sous la présidence du physicien hollandais Hendrik Lorentz, prix Nobel en 1902 pour ses travaux sur le magnétisme en lien avec les phénomènes radiatifs. Avec lui, la manière d'aborder la physique théorique prenait un nouvel et fructueux essor. Solvay venait de métamorphoser Bruxelles en un haut lieu d'échanges en matière de physique théorique.

«Fantaisies quantiques», par Catherine D'Oultremont et Marina Solvay, Editions Saint-Simon, 21,50 euros.

Des années de recherche, des interviews avec des scientifiques, des contacts privilégiés avec des descendants de participants du premier Conseil de physique. Marina Solvay a alimenté sa coauteure en informations de première main et en anecdotes éclairantes.

Marina Solvay, pourquoi proposer un tel livre sur les Conseils de physique et de chimie?
Depuis que je suis petite, je rencontre des physiciens et des chimistes de renom. Cela se passe en marge des Conseils Solvay mais aussi lors de réunions organisées par ma famille les années où aucun Conseil de chimie ou de physique n'est programmé (ils sont généralement organisés tous les trois ans avec une année blanche pour compléter le cycle). Quand mon père est décédé, voici une dizaine d'années, mon frère l'a remplacé à la présidence du conseil d'administration des Instituts de physique et de chimie Solvay, qui organisent les Conseils. C'est à ce moment-là que j'ai commencé à m'intéresser aux archives des Instituts, dont je suis devenue la présidente. Nous voulions revaloriser ces archives. Elles sont d'une grande richesse. On y retrouve entre autres des notes et des lettres qui font partie de l'histoire de la Belgique. Des lettres du Roi Albert à Hendrik Lorentz par exemple. La famille royale est liée à ces réunions scientifiques depuis leurs débuts. À chaque fois, le Roi participe à l'ouverture des Conseils. Les archives de ma famille ont également été examinées. Mais les archives des Instituts ont été dispersées, et j'ai rendu visite à l'ESPCI, où se trouve, en plein Paris, l'ancien laboratoire de Marie et Pierre Curie, et qui possède une grande partie de nos archives ramenées par Langevin après sa présidence.

Comment avez-vous «nourri» ce récit?
Nous avons commencé à travailler sur ce projet en 2014. Quelques mois plus tard, nous avons eu le bonheur de pouvoir rencontrer à l'hôtel Métropole les descendants des participants du premier Conseil de 1911, réunis par les Instituts Solvay. J'étais là avec mon frère et ma sœur, et Catherine d'Oultremont. Il y avait des descendants de Rutherford, d'Einstein. Nous avons aussi eu l'occasion de parler aux Joliot-Curie. Nombreux ont été les participants à cette rencontre qui nous ont livré des anecdotes, des histoires familiales liées au premier Conseil. C'est notamment comme cela que nous avons pu faire vivre ces personnages dans notre livre. En pratique, j'ai rassemblé énormément d'informations, d'anecdotes, d'archives. Je les ai partagées avec Catherine, qui a ensuite rédigé ce récit sur l'histoire des Conseils Solvay et leurs participants. C'est elle qui a tissé ce récit, dans la trame du XXe siècle, en décrivant les personnages qu'elle a très bien cernés.

«A l'époque, quand chacun de ces physiciens arrivait avec une nouvelle théorie, il était souvent taxé de fantaisiste. Y compris Einstein.»

Pourquoi avoir intitulé cette plongée dans l'histoire des Conseils Solvay «Fantaisies quantiques»?
Ni Catherine ni moi ne sommes physiciennes ou chimistes. Ce que nous avons écrit a bien entendu été vérifié, complété, corrigé par des chimistes, des physiciens et même des mathématiciens. Il aurait été prétentieux de notre part de dire que nous racontions une histoire de la physique quantique. Le terme fantaisie s'adapte donc mieux à l'esprit de notre livre. De plus, à l'époque, quand chacun de ces physiciens arrivait avec une nouvelle théorie, il était souvent taxé de fantaisiste. Y compris Einstein. Tout le monde n'a pas cru tout de suite à l'intérêt de ses théories. D'où ce choix terminologique de «Fantaisies» pour le titre de notre livre.

L'organisation des premières réunions était-elle une sorte de caprice d'Ernest Solvay?
Ce n'était pas du tout un caprice! La science, c'était sa passion, son cinquième enfant. Il nous l'a légué. Juste avant sa mort, il a réuni toute sa famille et lui a demandé de veiller sur ce cinquième enfant. Il a demandé à sa famille qu'il puisse survivre au moins pendant 50 ans après son propre décès. Mon père, mon grand-père et mon arrière-grand-père ont tous veillé au bien-être de ce cinquième enfant. Nous sommes aujourd'hui 100 ans plus tard, et les Instituts et les Conseils sont toujours là. L'œuvre de mécénat d'Ernest Solvay a été perpétuée.

Entre 1913 et 1921, aucun Conseil n'a été organisé. La Première Guerre mondiale explique bien entendu en partie cette interruption. Mais pourquoi avoir tardé jusque 1921 pour relancer la machine?
Il y a eu à cette époque un vrai problème pour l'organisation de ce Conseil. Principalement en ce qui concerne les invitations à adresser aux scientifiques allemands après la guerre. Hendrik Lorentz a eu beaucoup de mal à remettre en route un conseil qui soit vraiment équilibré. Ernest Solvay insistait beaucoup, et dès le début des Conseils, pour qu'il y ait un bon équilibre entre les nationalités des différents participants. Il souhaitait que le nombre de physiciens français soit égal au nombre d'Anglais et au nombre de scientifiques allemands, etc. Il avait réussi à atteindre cet équilibre. C'était dans un souci, disons, scientifique. N'oublions pas qu'à l'époque, chaque chapelle, chaque pays était différent en termes de recherche en physique théorique. Chacun travaillait dans son coin. Les chercheurs avaient du mal à se rencontrer. Brasser les idées à Bruxelles lors des Conseils de physique était dès lors très important. Après la guerre, il était donc difficile de reprendre des discussions équilibrées sans inviter les physiciens allemands, qui étaient très avancés sur le sujet des théories quantiques. *Les Allemands n'ont pu être invités qu'à partir de 1927, avec la permission du Roi. Cette situation explique sans doute le délai avant l'organisation du troisième Conseil de physique.*

Alors que la planète sort actuellement d'une longue période de confinement pour cause de pandémie de coronavirus, et que nous avons été habitués à «télétravailler» intensivement, le «format» des Conseils Solvay, qui mobilise les participants quasi reclus pendant plusieurs jours en un même lieu, est-il toujours bien d'actualité?
Les scientifiques que j'ai interviewés longuement dans le cadre d'un petit livre complémentaire d'entretiens me font tous la même réponse à cette question. Les Conseils sont tout à fait originaux et restent pertinents à leurs yeux. Ceci semble être d'autant plus vrai en ce qui concerne la physique théorique. Les scientifiques ont vraiment besoin de se réunir et de discuter des idées nouvelles qui sont lancées et de les étudier ensemble. Quand on participe à un Conseil Solvay, on s'engage à laisser ses outils de communication modernes en mode silencieux. On n'est pas interrompu par des e-mails, par des SMS, par des appels téléphoniques. On peut se concentrer entièrement sur les discussions du moment. Isolés ainsi pendant trois jours, cela débouche sur un travail intensif unique en son genre. Tout cela explique la pertinence et la richesse de ce genre de réunions.

L'organisation des Conseils Solvay à Bruxelles est intimement liée à l'hôtel Métropole. Ce lieu emblématique a accueilli de nombreuses réunions. Or celui-ci vient d'annoncer qu'il allait définitivement fermer ses portes. Cela pose-t-il un problème pour l'organisation du prochain Conseil de physique, prévu en 2021?
Nous savions déjà depuis environ un an que la famille Wielemans, qui dirige cet hôtel, avait décidé d'arrêter. Je ne sais pas ce que nous allons faire pour le Consei[l] d'octobre 2021. Je ne sais pas si le Métropole sera tou[t] à fait fermé ou s'il va être repris. Peut-être devien[-] dra-t-il un lieu d'organisation d'événements? Nou[s] avons prochainement un conseil d'administration de[s] Instituts Solvay. J'imagine que le sujet y sera à l'ord[re] du jour. Jusqu'à présent, c'est au Métropole que le R[oi] venait rencontrer les participants de chaque Consei[l]

SCIENCES

Les folles années du

Génie. Il y a un siècle, à Bruxelles, la crème des chercheurs réinventait la physique. Un livre retrace cette épopée collective.

PAR GUILLAUME GRALLET

Ne vous arrêtez pas à leur mine un rien chafouine, à l'intitulé docte du colloque « Électrons et photons », ou encore au fait que, sur les 29 personnalités prises en photo, 17 ont décroché un prix Nobel : le cliché ci-contre, pris en 1927 dans le parc Léopold de Bruxelles, rassemble sans doute la bande de scientifiques la plus rock'n'roll de l'histoire de la physique. Venus de l'Europe entière, de Cambridge, de Copenhague, de Göttingen, ils se rencontraient tous les quatre ans à Bruxelles, la plupart du temps à l'Institut de physiologie, mais aussi dans les salons Art nouveau de l'hôtel Métropole. Sur l'image, on reconnaît aisément Albert Einstein, Marie Curie ou Max Planck.

C'est cet âge d'or de la physique que relatent, dans *Fantaisies quantiques*, la romancière Catherine D'Oultremont et Marina Solvay, l'arrière-petite-fille de l'autodidacte passionné qui a découvert un procédé de fabrication de soude. Créateur du groupe de chimie basé à Bruxelles, il fut le principal mécène de ces rencontres. L'ouvrage retrace les fulgurances et doutes du Danois Niels Bohr, ceux du théoricien allemand de l'indétermination Werner Heisenberg et du génial Français Louis de Broglie. Tous travaillaient dans une sorte de fièvre collective : *« C'est à la main ou à la règle qu'ils faisaient leurs calculs, par lettres ou cartes postales qu'ils correspondaient, en bateau qu'ils traversaient les océans, en train qu'ils parcouraient l'Europe »*, note le physicien Étienne Klein dans sa préface. *« Alors qu'Alfred Nobel créa avec ses prix un système destiné à cou-*

MP/LEEMAGE

Max Planck (1858-1947) Initiateur de la théorie des quanta.

Marie Curie (1867-1934) Codécouvreuse de la radioactivité.

Erwin Schrödinger (1887-1961) Auteur d'une équation d'onde capitale.

Albert Einstein (1879-1955) Auteur de la théorie de la relativité.

quantique

Jules-Émile Verschaffelt (1870-1955) Cothéoricien de la physique moléculaire.

Paul Langevin (1872-1946) Théoricien du magnétisme.

Louis de Broglie (1892-1987) Découvreur de la nature ondulatoire de l'électron.

Niels Bohr (1885-1962) Initiateur de la mécanique quantique.

ronner des travaux aboutis, Ernest Solvay encouragea des chercheurs du monde entier à travailler ensemble pour résoudre des problèmes, cocréer et être à l'avant-garde de leurs disciplines. Ceci deviendra l'ADN de notre groupe », analyse la physico-chimiste Ilham Kadri, aujourd'hui à la tête de l'entreprise.

Ce bouillonnement intellectuel a tenté de percer les mystères de l'infiniment petit, et notamment l'interaction entre la lumière et la matière, à l'échelle la plus granulaire possible. Un monde où les échanges d'énergie se faisaient avec des quanta, des niveaux d'énergie bien précis déterminés par la fréquence de la lumière. Un feuilleton où les électrons, les photons et les atomes ont les rôles principaux. *« Comprendre leur interaction a joué un rôle crucial plus tard dans la création des GPS, des lasers, des panneaux solaires photovoltaïques ou encore de la fibre optique »*, explique le consultant en innovation et auteur Olivier Ezratty, qui y voit également un changement de paradigme.

Jubilation. *« Ce que cette discipline a de révolutionnaire, c'est qu'elle décrit l'état physique des systèmes, quels qu'ils soient, par une entité mathématique, la fonction d'onde. Celle-ci s'écrit, en général, comme la somme de plusieurs fonctions représentant chacune un état particulier, affecté d'un certain coefficient : c'est ce qu'on appelle une "superposition" d'états possibles. »* Car, du passé, il fallait faire table rase. *« Cette situation est sans équivalent en physique classique. La théorie stipule en effet que, connaissant la fonction d'onde, on ne peut en général pas déterminer le résultat d'une mesure, mais seulement calculer les probabilités d'obtenir tel ou tel résultat. Et parmi tous les résultats possibles a priori, un seul est sélectionné, au hasard, par l'opération de mesure »*, poursuit Étienne Klein.

Cette histoire est riche en moments de jubilation intellectuelle. Comme lorsque Niels Bohr, s'appuyant sur un dessin griffonné sur tableau, se vit, dans un salon marbré de l'hôtel Métropole, alpagué par Einstein : *« Laissons un moment l'incertitude et les probabilités de côté… Dieu ne joue pas aux dés, M. Bohr ! »* Ce à quoi le Danois ■■■

Échanges. Albert Einstein et Marie Curie à Genève, en 1925.

■■■ rétorqua : *« Mais qui êtes-vous, M. Einstein, pour savoir ce que Dieu fait ou ne fait pas ? »* Le débat reprit avec la même vigueur au petit matin ! Car le génie de ce livre est de retracer les histoires humaines. Il y est question de la passion d'Erwin Schrödinger, pour les... femmes. Le philosophe autrichien, fan de Spinoza, tenait un journal intime, qu'il avait intitulé *Les Éphémérides*, dans lequel étaient recensées non pas des équations mais ses conquêtes. Également bien décrite est la spiritualité d'Einstein, à travers cette lettre à un étudiant : *« Tout homme sérieusement impliqué dans la recherche scientifique devient convaincu qu'un esprit se manifeste à travers les lois de l'Univers – un esprit largement supérieur à celui de l'homme. [...] De cette manière, la recherche scientifique conduit à un sentiment religieux d'un genre spécial, qui est en vérité tout à fait différent de la religiosité de quelqu'un de plus naïf. »*

Téléportation. On revit également l'exil forcé du physicien qui, avant de partir pour les États-Unis, resta six mois dans la villa La Savoyarde, au Coq-sur-Mer, près d'Ostende. On y découvre aussi les voyages à dos d'âne de Marie Curie au Grand Canyon avec ses deux filles, Irène et Ève, elle qui sera invitée par Herbert Hoover à visiter la Maison-Blanche en 1929. Les recherches actuelles autour de l'intrication quantique, un phénomène dans lequel deux particules présentent des états dépendants l'un de l'autre, quelle que soit la distance qui les sépare, laissent entrevoir une possibilité de téléportation comme d'une informatique bien plus rapide... Décidément, il ne fallait pas se fier à la mine renfrognée de nos savants ■

EXTRAITS

« Fantaisies quantiques », de Catherine D'Oultremont et Marina Solvay (Éditions Saint-Simon, 452 p., 21,50 €).

La solitude de Marie Curie

Seule femme dans l'assemblée, *[Marie Curie]* observa les messieurs [...] ; certains portaient la cravate, mais la plupart arboraient des nœuds papillon aussi larges que leurs moustaches. [...] L'Anglais qui avait parlé au début était le seul qui dénotât quelque peu : il ne portait pas de moustache et son costume était gris clair. Voyant que Marie l'observait, il lui sourit de ses yeux bleus. Marie se concentra alors sur la voix grave de Lorentz.

« Dans cet état des choses, la belle hypothèse des paquets d'énergie, émise pour la première fois par M. Planck et appliquée à de nombreux phénomènes par M. Einstein, M. Nernst et d'autres, a été un précieux trait de lumière... »

Ondulatoire ou corpusculaire, ce trait de lumière ? demanda entre haut et bas l'éternel chahuteur qu'était resté Albert Einstein. Il y eut quelques rires et commentaires. Lorentz dut élever la voix pour faire taire l'assemblée.

« Messieurs, laissons de côté les traits d'esprit et revenons à nos moutons ! Cette nouvelle hypothèse nous a ouvert des perspectives inattendues. Elle mérite donc bien d'être le sujet principal de nos discussions. Et ceux qui ont contribué à son développement méritent que nous leur rendions un sincère hommage.

Nous remercions le professeur Franklin Lambert pour l'explication claire de cette affaire, qui marque, comme il le dit bien, l'avènement de l'ère quantique ! »

Nernst bomba le torse, tandis que Planck essuyait les verres de ses lunettes. Einstein eut un sourire de premier de la classe qu'on félicite pour son carnet de notes.

« Cependant, continua le président, *cette hypothèse n'est pas encore fermement établie... Il est donc indispensable que la nouvelle mécanique qu'induirait cette hypothèse soit aussi précise que la mécanique actuelle. Or ces précisions semblent encore faire défaut, ce qui est naturel étant donné le fait qu'elle n'est encore qu'une théorie naissante. Après les exposés de chacun, nous nous efforcerons de distinguer l'accessoire de l'essentiel. Quel sera le résultat de ces réunions ? Je n'ose le prédire, ne sachant quelles surprises vous allez nous réserver au cours de ces débats, n'est-ce pas, messieurs ? »*

Le regard de l'orateur fit le tour de la pièce, s'arrêta un instant sur Marie, à qui il sourit, comme pour s'excuser de l'avoir oubliée. Puis il regarda Solvay, assis à sa droite.

Une bière décisive pour Niels Bohr et Werner Heisenberg

[À l'issue d'une conférence, le professeur et l'étudiant boivent un verre au sommet du Göttinger Wald.]

« Avez-vous déjà imaginé ce que serait le monde si les atomes sortaient du périmètre de la matière qu'ils constituent ? Si les atomes de cette table en métal se mêlaient avec ceux de votre peau ? Tout cela m'a inquiété très tôt... »

Il fit une pause, avala une gorgée de bière puis reprit :

« Peut-être n'aurait-on pas prêté attention avant longtemps à ce miracle de la stabilité si certains chercheurs n'avaient pas osé aller plus loin, en apportant un éclairage nouveau sur le monde de l'atome. Une déduction en a apporté une autre... D'abord Planck a proposé que le rayonnement et la matière s'échangeassent de l'énergie par petits paquets, les quanta. Puis il y a eu les expériences de Rutherford. Je me souviens avec beaucoup d'émotion de mon séjour à Manchester, dans son laboratoire... C'est là-bas que je me suis familiarisé avec l'atome. »

[...]

« Nous savons aujourd'hui, reprit-il, *que la physique newtonienne ne peut être utilisée pour comprendre la structure de l'atome. [...] Notre situation est un peu comparable à celle d'un navigateur qui débarque sur une île dont il ne connaît rien des habitants et dont il ne comprend pas le langage. Il faut donc avancer en tâtonnant... »*

« Mais alors, lui demanda Heisenberg, *si la structure interne des atomes est aussi peu accessible à une description visuelle* [...] *et qu'en plus nous ne possédons pas les clés du langage qui permet d'en discuter, y a-t-il un espoir, d'après vous, que nous arrivions un jour à comprendre le mystère de l'atome ? »*

Bohr hésita, puis finit par donner une réponse sibylline :

« Oui, je pense... Ce jour-là, nous comprendrons ce que signifie le mot "comprendre"... » ■

ARCHIVES P. ET M. CURIE/AFP

« Revenons à nos moutons ! » Lorentz recadrant Einstein, éternel chahuteur, en plein débat sur la mécanique quantique

OVERVIEW OF

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

CHAIRS OF THE INTERNATIONAL SCIENTIFIC COMMITTEE FOR PHYSICS

1911 - 1928	Hendrik Lorentz 1902 Nobel Laureate in Physics, Haarlem (The Netherlands)
1928 - 1946	Paul Langevin, Paris (France)
1946 - 1962	Sir Lawrence Bragg 1915 Nobel Laureate in Physics, Cambridge (UK)
1962 - 1967	Robert Oppenheimer Princeton (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

CHAIRS OF THE INTERNATIONAL SCIENTIFIC COMMITTEE FOR CHEMISTRY

1922 - 1939	Sir William Pope, Cambridge (UK)
1945 - 1958	Paul Karrer, 1937 Nobel Laureate in Chemistry, Zurich (Switzerland)

THE INSTITUTES

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

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
2004 Nobel Laureate in Physics
Santa Barbara (USA)

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

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

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The Netherlands

2014 Richard Royce Schrock
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David Gross, Santa Barbara, USA
2004 Nobel Laureate in Physics

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Ernest Solvay, his son Armand Solvay and his grandson 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

IN PHYSICS AND IN CHEMISTRY

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2015 Peter Zoller, Innsbruck, Austria

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2017 Uri Alon, Rehovot, Israel

2018 Bernard Derrida, Collège de France, France

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2020 Roger Blandford, Stanford University, USA

2015 Andreas Manz, Saarbrücken, Germany

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2017 Richard Henderson
2017 Nobel Laureate in Chemistry
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2018 Ben Feringa
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2019 Gernot Frenking, Philipps-U. Marburg, Germany

2020 Joanna Aizenberg, Harvard, USA

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DIRECTORS

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1977 Nobel Laureate in Chemistry
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2004 - present Marc Henneaux
Professor ULB

THE SOLVAY PUBLIC LECTURES

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"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 (University of Cambridge, UK)

“The Brout-Englert-Higgs mechanism and its scalar boson”

by François Englert (ULB, Belgium)
2013 Nobel Laureate in Physics

18 October 2015 – One hundred years of Einstein’s general relativity

“Massive Black Holes and the Evolution of Galaxies”

by Reinhard Genzel (Max Planck Institute Munich, Germany)

“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)

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Editorial Director: Professor Marc Henneaux
Editorial account: Dominique Bogaerts
Design: Paola Connor, www.bluegrey.be
Prepress: BLUEGREY Graphic Design
Printed in Belgium

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Pages 29-31

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