Department d'évaluation
de la recherche

Research unit

Self-assessment document

EVALUATION CAMPAIGN 2018-2019
GROUP E

Please, refer to the "Guide for the redaction of a Self-assessment document" when filling in this application.

INFORMATIONS

Unit name: Institut de Physique Théorique
Acronym: IPhT
Hceres scientific domain and sub-domain: ST
ST2 Physique
ST1 Mathématiques

Director's name (current contract): François DAVID
Director's name (future contract): François DAVID

Application type:

Renewal (w/o important modifications ☒ Restructuration ☐ *Ex nihilo* creation ☐

List of supervising institutions and bodies of the research unit:

Current contract:	Next contract:
- CEA	- CEA
- CNRS	- CNRS

Inter-disciplinary evaluation for the research unit (or for one or more internal team):

Yes ☐ No ☒

Number of teams / number of themes for the next contract: 1/1

Requested label (UMR, EA etc.): UMR

SELF-ASSESSMENT DOCUMENT

The sections listed below must be completed in accordance with the frame below. The sections in italics will be deleted in the completed application.

1- Presentation of the unit

Introduction

History and location of the unit.

The Institut de physique théorique (IPhT) is a research institute of the Direction de la recherche fondamentale (DRF) of the Commissariat à l'énergie atomique et aux énergies alternatives (CEA), and of the Institut de physique (INP) of the Centre national de la recherche scientifique (CNRS, UMR 3681). It is part of the Paris-Saclay CEA centre, and is located in the (now open) site of Orme des Merisiers. It is part of the Paris-Saclay University project. It is situated on the Plateau de Saclay.

IPhT was founded in 1963, as the "Service de physique théorique", located in the Saclay main site. Since 1968 IPhT is located in its present buildings at Orme des Merisiers. Quickly, IPhT has gained and maintained over the decades a worldwide recognition for its many fundamental contributions to theoretical physics. Its long tradition of excellence and its early reliance on external and impartial scientific evaluations allowed the Institute to adapt to the many evolutions of theoretical physics from a purely scientific viewpoint, but also to the many changes in the management of science, in France and abroad. Its size in term of number of permanent scientists is now relatively stable, with a rough proportion of 2/3 of CEA researchers and 1/3 of CNRS researchers. In the early years the number of students and postdoctoral researchers was quite low (note that CEA had then higher funding for students, postdocs and visitors than more academic institutions). Since the 80's the number of students is much higher and the number of postdocs and long term visitors has increased enormously. They represent now about 60% of the researchers of the institute. They are mostly funded by external sources and grants. One should not forget the senior researchers with CEA and CNRS "emeritus" status, or members of the "Amis de la science" association (IPhT was probably the first unit in CEA to install such a program).

Structure of the unit.

Compared with other institutes or laboratories devoted to theoretical physics worldwide, the size of IPhT makes it one of the largest, in size and scope. It hosts slightly more than one hundred and twenty persons (see Table 2 below). The composition fluctuates rapidly due to the large number of temporary researchers: the order of magnitude is twenty or thirty PhD students and thirty Postdocs. There are about fifty permanent researchers, two thirds CEA and one third CNRS. The support team comprises 8 persons (seven CEA and one CNRS employee), some of whom are shared with other labs of the DRF (librarian with IRAMIS/SPEC, system administrators with LSCE).

Despites this large size, IPhT works as a whole and is not structured in teams or laboratories. The functioning of the Institute is steeped in collegiality. The research themes cover most of the active subjects in theoretical physics. They can be grouped in three main themes, that we have used for this report

- Mathematical physics – structures and model
- High energy physics and cosmology
- Statistical and condensed matter physics

The researchers are affiliated to three thematic "groups", which are labelled by tradition "A", "B" and "C". They roughly span the above-mentioned themes. These "groups" are rather lightweight structures. Their function and role will be described in sect. 4. There is no clear-cut division of researchers into big themes, working separately of each other's. Researchers rather work in small collaborations, very often with outside collaborators, on a given problem or program, but this is often a dynamical process. Of course, at a given time some large source of funding (typically an ERC grant) federates for a few years a larger group involving one (or a few) permanent researcher, postdocs, graduate students and visitors on a given program.

The support staff is common to everyone in the Institute.

Organisational chart (in appendix 3, see page 5).

Workforce and resources of the unit

Please, fill out the Excel files "Données du contrat en cours UR " and "Données du prochain contrat UR".

Here, please provide comments on the evolution of the workforce and resources during the current contract.

Workforce:

Permanent positions

Between 2013 and mid 2018, five permanent scientists entered the Institute : B. Bellazzini in 2013 (CEA), M. Schiro in 2014 (CNRS), J.-J. Carrasco in 2015 (CEA), P. Urbani in 2016 (CNRS) M. Guica in 2016 (CEA).

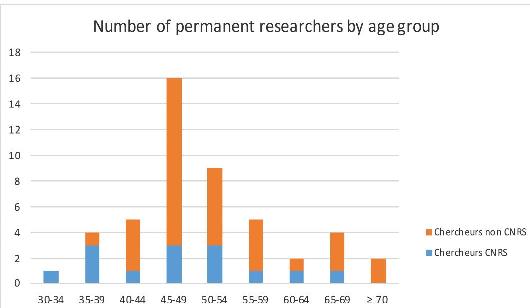
In the same period four researchers have left or will leave the Institute in 2018: M. Cirelli (CNRS) in 2015, C. Caprini (CNRS) in 2016, S. Nonnenmacher (CEA) in 2018 (on leave since 2015 as Professor at Institute of Mathematics, U. Paris-Sud), G. Biroli (CEA) in 2018, Professor Ecole normale supérieure.

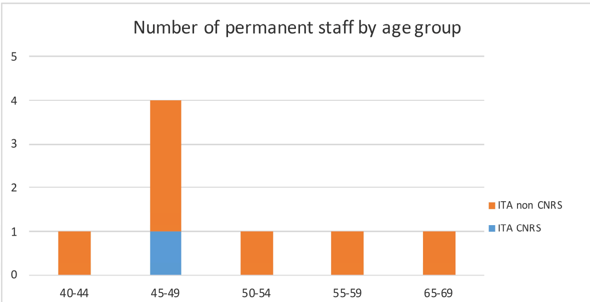
Four researchers are presently on leave, two on a "détachement" CEA position: R. Britto since 2014 (Dublin) and O. Parcollet since 2018 (Flatiron Simons Institute, New-York, USA). Two are away on a CEA position ("mise à disposition") : F. Bernardeau since 2014 (IAP-Paris as Director) and J. Bouttier since 2016 (ENS-Lyon).

The support staff has been in weak decline. Our administrative deputy director Anne Capdepon left in 2013 (for USCI-Saclay) and has been replaced by Anne Angles in 2014. C. Cataldi, administrative assistant (CEA) moved to SER in 2013 and has not been replaced. Since end 2011 we have a CNRS administrative assistant. Since 2018 C. Roger-Roulling fills this position. The rest of staff has been stable (six CEA).

1CNRS retirement took place during the period (Jean –Paul BLAIZOT) and a CEA retirement is announced for October 2018. This lack of departure for CNRS is simply due to the ages of the CNRS scientists, the compulsory retirement age for CNRS is presently 66 years. For CEA this is due to the fact that there is no compulsory retirement age any more, and to the fact that CEA researcher with full pension rights chose to pursue their activity during the period.

Note that two of our most esteemed retired colleagues (who enjoyed emeritus status and had kept an office at IPHT) passed away during the period: André Morel in 2013 and Cirano de Dominicis in 2017. Both had been directors of the Institute.





Non-permanent positions

During this same period we welcomed:

57 PhD Students

95 Postdocs

82 trainees

Resources:

Allocated to IPhT

The CEA dotation (it includes incomplete support for the CEA salaries) is by far the largest fixed resource. It went down by 7.7% from 2013 to 2017. This trend will continue in 2018.

The CNRS dotation is very low and stable. It does not include the salaries.

Contracts

Our proper resources come from external contracts, and of course vary from year to year (see table). They come firstly from ERC grants, then from ANR grants and PIA programs (through Paris-Saclay), and some miscellaneous sources. Contracts managed by CEA or CNRS researchers go through their respective institutions.

Seven ERC grants ended in the 2013-2018 period.

Eight new ERC grants entered into force in the same period.

One European International Training Network was hosted at IPhT

We also benefited from private fundings: Templeton and Simons foundation.

CNRS	CEA	Acronyme	Responsable Scientifique	Date début	Durée du contrat	Date
	x	*MM-PGT*	*Kosower D.*	***01/01/09***	*72*	*31/12/14*
	x	*String-QCD-BH*	*Bena I.*	***01/01/10***	*60*	*31/12/14*
	x	ObservableString	Grana M.	**01/02/11**	68	30/09/16
	x	NanoGraphene	Bena C.	**01/05/11**	60	30/04/16
x	x	QCDMAT	Blaizot J.-P.	**01/08/11**	60	31/07/16
	x	NPRGGLASS	Biroli G.	01/11/11	72	31/10/17
	x	MottMetals	Parcollet O.	01/01/12	72	31/12/17
x		NewDark	Cirelli M.	**01/10/12**	72	*Transfered to DR2*
x		ITN Gatis	Serban D.	**01/01/13**	48	31/12/16
		CutLoops	*Britto R.*	*Transfered to Dublin*		
	x	preQFT	Carrasco JJ	**01/06/15**	60	31/05/20
	x	Nu QFT	Saleur H.	**01/10/15**	60	30/09/20
	x	CHAMPAGNE	Pepin C.	**01/08/16**	60	31/07/21
	x	Emergent-BH	Guica M.	**01/09/16**	60	31/08/21
x		SMiLe	Zdeborova L.	**01/09/2017**	60	31/08/22
	x	Stringlandscape	Grana M.	**01/09/2018**	60	31/08/23
	x	QBH	Warner N.	**01/01/2020**	60	31/12/2024
	x	**Templeton**	Bena I.	**01/04/2014**	33	31/12/2016
	x	**SIMONS**	Parcollet O.	**01/03/2015**	48	28/02/2019
	x	**SIMONS**	Biroli G.	**01/05/2016**	48	30/04/2020

Scientific policy

Please describe here the missions, scientific objectives and strategy of the research unit for the current contract, as well as unit's national and international position. Please dispatch the unit's activities between basic research, transfer of knowledge and research support; this will help characterizing the unit, most notably for the labs deeply involved in knowledge transfer. Describe the unit's management, scientific animation, etc. Describe the actions taken in response to the recommendations of the previous site visit committee.

Mission:

The mission of Institut de Physique Théorique is to perform research in mathematical physics, quantum field theory, high energy and nuclear physics, astrophysics, statistical physics and condensed matter physics. Our main activity is basic research in theoretical physics, resulting in the publications in peer-reviewed journals (articles, reviews), as well as communications in international conferences or workshops, or in various seminars. We also take part in the organization of such events. Publication of books on advanced topics is also part of our research activities. We include scientific management of grants and contracts in this activity. Globally this activity may accounts for 80% of our time.

Many IPhT researchers dedicate a significant amount of time to the formation of students, mostly at the graduate level (master students or PhD). Many researchers regularly teach in Master courses, at IPhT, in the Paris area but also farther in France or abroad (within and outside Europe). We also organize or teach in numerous summer schools. The number of graduate students present in the institute has grown rapidly in the last few years, it almost reaches 30, to which should be added about 10 external PhDs spending a long period in our Institute. Roughly 15% of our work time can be associated with this formation activity.

Research administration and animation may account to about 5% of our work time. It mainly consists in participation in various committees: hiring committees at universities, CNRS committee, steering committees of various research structures (Labex, RTRA, academic senate of the new Paris-Saclay University).

Outreach and dissemination of science towards society at large are still relatively few. We have neither specific IPhT structure nor special budget for this. We are aware that this is important and that actions should be increased. Several researchers, on an individual basis, participate to such actions: general public conferences in Saclay or in high schools, participation to radio or web actions. Writing or participation to outreach or history of science books, or to general public science publications (La Recherche, Pour la Science). One new activity which started during this contract is the organization, at IPhT, of an internal "Séminaire de Vulgarisation" (outreach seminar) for non-researchers people working at IPhT and in the CEA units.

Position:

IPhT can claim to harbor at least one respected specialist in any major physics field of current interest, with a handful of exceptions though. Let us recall that the previous site visit committee in 2013 acknowledged *"the very high scientific level that the laboratory has maintained through the last period, which makes it one of the top laboratories in Europe for theoretical physics."* Of course it is the task of this committee to evaluate if we have kept, or maybe improved our rank. But owing to our number of publications, of prizes and grants awarded to some of our researches, and the quality of the young scientists which entered the institute, or spend some time during the 2013-2018 period, we think that this period has been a very rich and interesting period for the Institute.

Management and Animation:

The management and structure of the unit is briefly described in page 3. At this point, since the Institute is not subdivided into "Services" and "Laboratories", we prefer to defer to section 4 (Organisation and life of the research unit) for a more detailed presentation.

Actions in response to the previous site visit committee:

The previous site visit committee had a number of recommendations that IPhT did its best to address:

<u>Recommendations 1 (pages 7 and 10):</u>

"The Institute should improve significantly the involvement in the shaping up of the Paris Saclay research pole, which should see positively an active role of one of the leading laboratories in theoretical physics. IPhT might increase its influence by teaming up with other theory laboratories in the area."

"As emphasized in the plan proposed, the presence of IPhT in the Paris Saclay pole is an opportunity that must be seized. The laboratory should strengthen its connections with the other theory laboratories in the pole in order to enhance the overall visibility and influence of theoretical physics."

Response:

IPhT (especially my predecessor M. Bauer) was aware of the problem. It turned out that this was not that easy, for the following reason. The structuration of UPSay in three Departments for Physical Sciences and one for mathematics implied that the research units in theoretical physics in UPSay are separated or shared by at least two Departments. In the case of IPhT, as we shall explain in the next section, we are shared between **four** Departments. The fact that the various present partners : Université Paris-Sud, Ecole Polytechique, CEA and CNRS still had often distinct view on the future of UPSay did not helped during the past period. IPhT kept a practical point of view and worked at developing low-level actions and partnership between different units. See next section for example of such actions, which were possible through the present organization. One may hope that in the near future, a possible reorganization into "poles" for research and "graduate schools" for education, with a single larger entity for "Physical Sciences" as a whole will help to make theoretical physics in UPSay more than the sum of its parts, more visible and more active. On the negative side, the fact that Ecole Polytechnique left UPSay to start its own "NewUni" university project will make things more difficult, since we have already relations and collaborations with CPT-X (as well as will other physics and math laboratories of Ecole Polytechnique).

<u>Recommendation 2 (page 10):</u>

"The committee supports the move to consider tightening the link with CNRS (and possibly the Paris Saclay pole) by changing the status of the laboratory from URA to the more standard "Unité Mixte de Recherche")."

Response:

This is done

<u>Recommendation 3 (page 14, about mathematical physics):</u>

"Members should find the best ways for using the new types of funding in a collaborative way. They should get closer to the University, where they could find new opportunities of recruitment of students, of funding, hiring, and stability."

Response:

Point 1: We hope to have taken steps towards the first suggestion. Note that several ERC grants have been obtained in this field, and are used in a not closed way. Researchers not in the main theme of an ERC may benefit from it if their interest is related. One can also note that there has been fruitful collaborations between researches affiliated to different ERC or ANR grants.

Point 2: For reasons already discussed in the response to recommendation 1, this is quite difficult to achieve in the present context. There is no possibility to become an UMR CEA/CNRS/University at the moment. A presently discussed convention which will allow CEA/CRS UMR to become "affiliated to UPSay" will not give us access to Teaching+Research positions. We are sorry to say that is it easier for our former students and postdocs to get a position in a foreign university than in France, especially in Paris-Saclay…

<u>Recommendation 4 (page 17, about particle physics and astrophysics):</u>

"It is recommended that the researchers in cosmology and physics beyond the Standard Model aim at collaborating more, in order to build on the strength of their individual research. This is even more important after the departure of some senior members. Sharing post-docs or Ph.D. students might help in this respect."

Response:

We think that some collaborations built up, especially in response to the dramatic development of gravitational wave physics. One the other (negative) side, two more young senior members left.

Recommendation 5 (page 21, about Statistical physics and condensed matter):

"Members are encouraged to explore the possibilities of developing more common projects within the group. As a step in this direction, post-docs could be encouraged to work with more than one member of the group."

Response:

The quality and originality of the research in this theme stayed very high, and possibly went higher. Nevertheless, we are not sure the suggestion has been followed. This is partly due to the fact that the funding stayed based on large individual grants.

2- Unit's environment

Here please describe the local structures ("pôle, champ de recherche, Institut", etc.) in which the unit is involved, specifying the scientific objectives, the resources (technical, human or financial resources), and the added value for the unit (scientific outputs, reputation and appeal or technology transfer).

CEA

The Institut de Physique Théorique is a research unit of the Direction de la Recherche Fondamentale (DRF) of CEA (Commissariat à l'Energie Atomique et aux Énergies Alternatives). It had a longstanding relationship with CNRS and is since 2015 an UMR (Unité Mixte de Recherche). See Section 1. for a few more details.

During the present contract, a reorganization of fundamental research in CEA occurred. The Division of Physical Sciences (DSM = Direction des Sciences de la Matière) and the Division of Life Sciences (DSM = Direction des Sciences de la Vie) merged into the new Division of Fundamental Research (DRF = Direction de la Recherche Fondamentale). Some reorganizations and reshufflings within Institutes and Laboratories of DRF occurred (and are still ongoing in Grenoble). Shorlty after, the two Saclay and Fontenay-aux-Roses Centers were united in a single Paris-Saclay CEA Center. This later reorganization does not affect us directly.

IPhT is at the same level that other Departements, such as the LSCE (Laboratoire des Sciences du Climat et de l'Environnement) and IRFM (Institut de Recherche sur la Fusion Magnétique). It depends directly of the Directeur of DRF. The place and missions of IPhT within CEA and DRF are recognized and made precise by a document "Status et Mission de l'IPhT" approved by the AG and the HC. See appendix.

DRF is of course our main interlocutor and the main source of allocated resources to IPhT, CEA salaries, building and computer infrastructure, financial and HR support, administrative support for collaborations (for us mainly with European and Foreign institutions and funding agencies). We also get support from DRF for schools and conferences.

The scientific environment of CEA-Saclay has always been and is very important for us: IRFU for High Energy Physics and Astrophysics, IRAMIS, especially SPEC for Condensed Matter and Quantum Physics. Our contacts with INAC in CEA-Grenoble are also very important for our Condensed Matter theorists.

CEA has a "Filière Expert" of selected researchers and engineers who can be called for advices and missions in their fields of expertise, outside their own lab or institute. It should be noted that IPhT has a large numbers of experts at the various levels. They could probably be used more often.

DRF has launched an incentive DRF-Impulsion program for starting collaborative interdisciplinary actions, especially between matter and live sciences laboratories. Proposals are evaluated and selected by a panel of experts and the scientific direction. IPhT participates to this new programs (our proposals have all been selected) and this allow us to start programs in new and interesting directions (biomolecules, neurosciences).

One of our mission within CEA and to develop connection and to provide theoretical expertise to other institutes within DRF and to other divisions. A program to host for short period (part or full time) researchers from and outside DRF has been discussed with the Scientific Directions of the Divisions of CEA (DRF, DEN, CEA-TECH and DAM)and is ready to be implemented.

CNRS

IPhT has been since a long time one of the largest CNRS unit for theoretical physics in terms of its number of CNRS researcher. It is a unit with UMR status since 2015. IPhT belongs to and is managed through the DR4 (Direction Régionale Paris-Sud). CNRS provides mainly HR support through the salaries of its researchers, and since 2011 of one administrative assistant (much needed). IPhT is member of various GDR (Groupements de Recherche), benefits from various CNRS collaborative programs (ACI, etc.). Through the personal contacts and collaborations of IPhT researchers with others UMR (mostly CNRS/Universities) in Paris-Sud and Paris-Centre, IPhT is fully integrated, and in many areas plays a leading role, in the web of CNRS and Academic laboratories in theoretical physics, high energy and condensed matter physics, but also astrophysics and mathematics.

PARIS-SACLAY

Of peculiar interest and relevance is the project of the Paris-Saclay university (UPSay) and the eponymous Idex. IPhT has been and is involved in this project in several ways, at various levels. Since 2013 the project has undergone several episodes (some thrilling) and has yet to fulfill all of its expectations. The next important step in 2020.

LABEX

IPhT is member of three Labex, which through the PIA programs provide sources of additional fundings.

- Labex Hadamard (LMH, Mathematics)
- Labex P2IO (Physique des Deux Infinis et des Origines = High Energy and Nuclear Physics, Astroparticles and Cosmology)
- Labex PALM (Physique : atome, lumière, matière)

During the period, 4 postocs got support from LMH, 2 postocs and one student from P2I0 and 4 postdocs from PALM. The three Labex provided funding for conferences and visitors.

DEPARTEMENTS

At the moment UPSay is organized into several Departments. These Departments have some funding through the UPSay, smaller than those of the Labex. They have some support and incitative programs. They provide also a framework for prospective, coordination of research, and dissemination of information. IPhT is affiliated to four Departments of UPSay.

- Hadamard (Mathematics, more or less parallel to the eponymous Labex)
- P2I (Physique des deux Infinis = High Energy, Nuclear Physics, Astroparticles)
- PhOM (Photons, Ondes, Matière, includes thematics of PALM, but more)
- SPU (Sciences de la Planète et de l'Univers ; for IPHT the Cosmology part)

The complete list of actions partially or full through the Idex, Labex and Departments can be extracted from the tables in XXX. Let us mention a few ones, which are somehow iconic.

Ψ2 and IPa

The Ψ2 (Paris-Saclay International Programs for Physical Sciences and their Interfaces) is one of the 13 "Initiatives de Recherche Stratégiques" funded by the Paris-Saclay University. It funds and organizes a series of international thematic programs (4 to 8 weeks). Every program is focused on a precise theme in Physics, or at the interface between Physics and other disciplines. They are based on long-term visits (≥2-3 weeks) of international researchers, in an environment that stimulates new ideas and new collaborations.

IPhT participates to this program through its board (one member, G. Misguich is from IPhT), and especially because it hosts some of the sessions (together with IAS in U. Paris-Sud). We allocate some offices and some open space (after some refitting and refurbishment) for hosting the visiting scientists during the programs, and make available our seminar and conference hall.

The Ψ2 programs are a first step in the more ambitious Institut Pascal project (IPa) which is expected to be operational in 2019, in a dedicated building on the Plateau. U-Psud, CEA and CNRS are partner of this Paris-Saclay project. IPhT fully supports it, and plans to contribute to its activities.

For info, see: https://www.universite-paris-saclay.fr/en/institut-pascal

SÉMINAIRE ITZYKSON

The "séminaire Itzykson" is an LMH program, organized jointly by researchers from IMO (Institut de Mathématiques d'Orsay), from IHES and from IPhT. It is a Mathematics and Physics one-day colloquium which takes place twice a year at IHES. The titles of the past sessions have been: *Chaos quantique, Cartes planaires et gravité quantique, Wall crossing in Hitchin integrable systems, Espaces de modules et courbes quantiques, Feynman Integrals, Physique statistique hors équilibre, Résurgence et quantification, Parafermionic observables and 2D statistical physics.* For info see:

https://www.fondation-hadamard.fr/fr/lmh-mathematiques-et-physique/lmh-seminaire-itzykson

Plateau de Saclay Campus:

Last but not least, practical issues ! The access to IPhT from Paris-Centre and from the RER-B stations has improved with the opening of new bus lines via a dedicated road ("voie en site propre") from the RER-B Massy-Palaiseau station. The "voie en site propre" is also a bicycle lane, which makes coming by bike to IPhT a much safer and pleasant journey. Nevertheless, this improvement is impaired by the increasing unreliability of the RER-B line, and by the serious traffic problems created by the road works and construction works taking place on the plateau. So both the objective gap and the psychological gap between the plateau and the valley still exists.

3- Research products and activities

A- Mathematical physics - structures and models

This theme spans a wide range of topics, from almost pure mathematics to some works which may be related to experiments. Despite this variety, many of these subjects are connected by the fact that they use common tools (Quantum Field Theory, integrable systems, conformal field theory, string theories, random matrices, combinatorics, probabilities, etc), many of which have been developed over the years at IPhT. On several subjects, contacts and collaborations between IPhT and mathematicians develop quickly. This does not reflect a move towards more abstraction, but a genuine interest of mathematicians for problems from physics, and of physicsts for the ideas and the new mathematical tools develops by mathematicians. This cross-fertilization finds an ideal playground in the "triangle" IPhT-IMO-IHES. But mathematical physics at IPhT also has close contacts with statistical physics and high energy physics, e.g. with important progress made on the problem of evaluating scattering amplitudes, which is now finding its way in LHC phenomenology.

Quantum Systems and Mathematics

Quantum non-demolition measurements When subjected to indirect non-demolition measurements, the evolution of a quantum system under a deterministic conservative (Hamiltonian) or dissipative (Lindbladian) dynamics becomes stochastic. A parameter controls the interpolation between the deterministic regime when measurements have a very small effect, and a stochastic regime dominated by quantum jumps triggered by the measurements. Our results [t14/357, t15/249] give a complete picture of the highly stochastic regime. The correlation function for a finite number of times can be computed in terms of some explicit effective Markov process and our predictions are consistent with actual experiments exploring this fascinating realm. Surprisingly, correlations involving an infinite number of times may exhibit anomalies, involving aborted quantum jumps that we call spikes. The mathematical description of spikes forced us to conjecture and prove new limit theorems for stochastic differential equations, actively studied by mathematicians. There is some hope that these anomalies can be seen in real experiments in a foreseeable future. Our techniques opens also the way to original analysis methods for more general intermittent signals, as in turbulence and seismology.

Escape rates, hyperbolicity and chaos In the presence of a scattering potential, an initially localized quantum wave function will "escape" towards infinity in the long time limit. In the semiclassical regime, the associated escape rate is highly influenced by the classically trapped set, i.e. Hamiltonian trajectories which do not escape to infinity. In [t13/148], we consider the case where this set forms a normally hyperbolic symplectic submanifold of the phase space, a situation relevant e.g. for the dynamics of chemical reactions or when studying wave propagation on a Kerr black hole in general relativity. We show that the decay rate of the quantum correlations is then related to the transverse hyperbolicity of the Hamiltonian flow. Paradoxically, this "quantum" result allows to also recover properties of the correlation decay for strongly chaotic (Anosov) classical flows.

Riemann Hypothesis A new progress was presented in [t17/030] around the celebrated Riemann Hypothesis (RH), a major conjecture of number theory about the Zeta function. The RH admits an apparently simple criterion, given by X.-J. Li in 1997, based on the behavior of a specific (Keiper-Li) sequence, whose terms are however very hard to calculate. We obtained a totally explicit and elementary variant of this sequence leading by semiclassical analysis to a new criterion: if the RH is true, the new sequence grows logarithmically; if it is false, the sequence eventually oscillates with amplitude increasing as a power law. A first multi-precision parallel programming allowed to reach the index $n = 500000$ (compared to 100000 for Keiper-Li) but a real test of the RH would require reaching $n = 10^{13}$. For a more general Zeta-type function (Davenport-Heilbronn) which clearly violates the RH, the increasing oscillation of the new associated sequence is visible from $n = 100$, confirming the proposed new criterion.

QFT and CFT

Renormalization group flow The renormalization-group flow equation describes the evolution of the effective action of a regularized quantum field theory in terms of its infrared cutoff. The renormalized quantum field theory is recovered by taking the limit that removes the cutoff. The renormalization-group flow equation can be expanded perturbatively in the Planck constant, and solved recursively. This allows us to rigorously prove properties of renormalized correlators at all orders of perturbation theory, without computing Feynman diagrams.

We have demonstrated this technique in the case of a simple pure gauge theory [t17/055]. In this case we have proved that the cutoff-removing limit exists, and that the renormalized theory has a Becchi–Rouet–Stora–Tyutin symmetry.

Conformal bootstrap The conformal bootstrap methods consists in classifying, defining and solving conformal field theories using only symmetry and consistency assumptions. This method can lead to exact results in two-dimensional theories, thanks to their infinite-dimensional symmetry algebras. In particular, a discrete family called minimal models has been solved in the 1980s.

We have extended this method to continuous families of theories. This is motivated by models that have a continuous parameter (the central charge), such as the 2d Potts model. Having a continuous parameters shifts the emphasis from the algebraic analysis of the structure of representations, to the analytic properties of correlators.

We have thus built and solved continuous families of both diagonal [t15/048] and non-diagonal theories [t17/203]. The family of diagonal theories is called Liouville theory with a central charge less than one. We have found an interpretation of this theory in terms of microscopic loop models, which paves the way to applications to statistical physics [t15/260].

Lattice regularization of CFT Conformal field theories that are relevant to various condensed-matter systems in 1+1 dimensions can be not only non-unitary, but also logarithmic. In order to disentangle the complicated structures of their spectrums, we have introduced lattice regularizations of these theories. Lattice regularizations have symmetry algebras such as the Temperley–Lieb algebra, and can be analyzed using known mathematical techniques [t17/220].

The next step of the program is to recover the properties of the continuum theories from their lattice regularizations. Out of the building blocks of correlators in the conformal bootstrap approach, we have already recovered structure constants [t15/260], and we believe that we can tackle conformal blocks too.

Non-unitary theories Non-unitary quantum field theories in 1+1 dimensions appear naturally in the description of a variety of gapless systems of statistical mechanics, such as percolation and polymers, or quantum critical points separating the plateaux in 2+1-dimensional topological insulators. The loss of unitarity can be traced back to either weak non-locality, or averaging over disorder.

In order to study renormalization group flows in the absence of unitarity, we have shown that it was fruitful to study the behaviour of entanglement entropy [t16/185], rather than trying to generalize Zamolodchikov's C-theorem. We have also shown that continuum limits of non-unitary spin chains can be conformal field theories with continuous spectrums, and demonstrated this in the case of a well-known model for tricritical polymers [t14/134].

Integrable systems

Cluster algebras, dimers and tiling models Cluster algebras, invented as a pure combinatorial structure, found many applications in mathematics (representation theory,..) and statistical physics. In a nutshell, a cluster algebra is a multi-time dynamical system describing the evolution of variables via mutations. In [t13/326], we explored the link between the cluster algebra structure of the solutions to the abstract T-system satisfied by transfer matrices of integrable quantum spin chains and the statistical mechanics of dimer models on certain graphs called networks. In particular, partition functions on fixed domains correspond to mutation invariants. In [t15/221], a quantized cluster algebra structure was used to compute graded tensor product multiplicities of representations occurring in inhomogeneous quantum spin chains, generalizing the difference Toda equation.

Baxter's TQ relation in quantum chains and exclusion processes The Bethe ansatz is a standard method for addressing integrable models, but it does not always apply. Then we can fall back to Baxter's TQ relation: a difference equation for two commuting operators that depend on a spectral parameter. In particular, this relation leads to a non-linear equation from which the model's spectrum can be deduced.

We have identified the two relevant operators in a number of interesting models, including the the Ruisjenaars–Toda chain [t18/029] and the Asymmetric Simple Exclusion Process [t14/324]. In the latter case, this has allowed us to rederive the fluctuations of the current.

Integrable gauge theories We have focussed on the planar limit of a maximally supersymmetric four-dimensional gauge theory, which on the one hand can be viewed as a toy model for quantum chromodynamics, and on the other hand is dual to string theory in Anti-de Sitter space.

While the spectral problem in this theory is in principle solved, computing correlators is a challenge that goes well beyond standard integrability techniques such as the Bethe Ansatz. We have been developing other methods, using integrable spin chains, separation of variables, or infinite-dimensional symmetry algebras. In particular, we have shown that three-point functions have a Yangian symmetry in the weak coupling limit [t14/231].

We have been particularly interested in the limit of heavy fields, where the model is dual to classical strings. We have computed some three-point functions in this limit, and found agreement with string theory [t16/029].

Topological recursion and enumerative geometries

Topological recursion Since 2007, we have been developing topological recursion [t14/033], a method for systematically computing asymptotic expansions in matrix models, enumerative geometry, and integrable systems. Recent works support the claim that in integrable systems, topological recursion can systematically compute not only WKB-like expansions, but also non-perturbative contributions [t16/056].

This provides a geometric framework for all known integrable systems (including conformal field theories), where the systems' properties and in particular their Tau functions can be built from the geometry of a spectral curve [t13/281].

Enumerative geometry Enumerative geometry consists in counting the number of possible configurations of geometric objects, typically surfaces immersed in a target space. The surfaces can be either discrete, so that counting them is a problem of combinatorics, or continuous, as in string theory. We have focussed in particular on discrete surfaces, for example knots in the three-dimensional sphere or in a Seifert manifold [t14/310].

Two-dimensional random geometry

Two-dimensional random geometry is a major field of research, with both physical (string theory, 2d quantum gravity, membrane modeling) and mathematical motivations (integrable systems, exact combinatorics). Our Institute has a number of experts in the field, whose activity covers a large spectrum of approaches, from discretized surface combinatorics to continuous models.

Random maps Random maps (graphs embedded in a 2d surface) provide a discrete version of 2d random geometry, amenable to exact enumeration. Powerful tools for map combinatorics were developed in our Institute. Among recent remarkable results is the computation of the "three-point function" of general planar maps, which is the distribution of pairwise graph distances between three arbitrarily picked vertices on a random map [t14/029]. Universal laws were obtained in [t16/015] for the statistics of the "hull perimeter", which is the length of the closed curve separating two arbitrary vertices and lying at a fixed distance from one of them.

Other results concern Voronoi cells within maps: choosing k vertices uniformly splits the map into k cells gathering vertices closer to one chosen vertex than to the others. A conjecture by Chapuy (2016) claims that the law for the volume fraction of the k Voronoi cells (i.e. the proportion of the map occupied by each cell) is that of a uniform k-division of the unit interval. A proof of this conjecture was given in [t17/031] in the simplest case k=2.

Another open question is that of the geometry of maps decorated by statistical mechanics models. In [t16/170], pursuing an original combinatorial approach to the O(n) loop model that we developed earlier, we studied the properties of nestings between loops. Interestingly, these are characterized by an explicit large deviation function which may alternatively be computed using the formalism of Conformal Loop Ensembles (CLEs) and Liouville field theory. A complementary study was done in [t17/130] : the tree describing the nestings was shown to converge to an explicit multiplicative cascade.

Random Delaunay A new model of discretized 2d gravity based on random Delaunay triangulations was introduced in [t13/189]. This model, which generalizes random maps and circle-packing embedding methods, is explicitly conformally invariant, and may be viewed as a discretization of the 2d Polyakov string. We proved that the model can be mapped onto some topological models of 2d gravity and studied its conformal properties from the point of view of deformation of integrable isoradial structures.

Interacting Liouville theory A continuous version of 2d random geometry is provided by the famous Liouville field theory (LQG for Liouville Quantum Gravity). A first rigorous construction of the theory by probabilistic methods was obtained in [t14/173] (collaboration with ENS, UPEM and U. of Helsinki), which presents a construction of the measure and of the correlations functions on the Riemann sphere and on the torus, gives a proof of its conformal invariance and of the KPZ relations, and constructs the puncture operators. This work eventually led to the proof of the DOZZ relations.

Liouville, SLE and CLE In [t14/325], we present a way to glue a coupled pair of Continuous Random Trees (CRTs) to produce a topological sphere and to canonically embed it in the Riemann sphere. The associated random measure is that of LQG, while the random interface between the trees becomes a space-filling Schramm-Loewner Evolution (SLE). The precise law of the coupled CRT pair was earlier shown to exactly correspond to the scaling limit of a random planar map decorated by Fortuin-Kasteleyn clusters. This provides the first proof that the latter scale in a certain topology to LQG decorated by a CLE.

In [t15/087] and [t17/147], we provide a generalized and complete description of the integral means spectrum of whole-plane SLE, a conformally invariant random map of the unit disk to the slit plane. Five phase transition lines are shown to partition the moment plane, implying in particular the incompleteness of a 2009 proof by Beliaev and Smirnov that is finally repaired here.

String theories

Black holes microstates geometries In the context of supergravity theories that emerge as low-energy limits of string theory, we have constructed the largest known class of solutions, parameterized by a continuous function of two variables, that have the same charges, mass and angular momentum as a black hole, but have no horizon [t15/051] and argued that counting these "superstratum" solutions can reproduce the black hole entropy [t14/272]. We have also succeeded in constructing the superstratum microstate geometries with arbitrary small angular momenta corresponding to microstate of non-rotating black holes [t16/067]. We have also been able to construct microstate geometries for non-extremal black holes [t15/188] and have understood the mechanism preventing these geometries from collapsing into a black hole [t13/059].

(In)stabilities of dS vacua We have shown that all anti-D3 brane solutions in certain flux backgrounds must have a certain singularity, which cannot be resolved by cloaking with a black hole horizon [t13/079]. Therefore the final solution is not meta-stable, as previously believed, but unstable both at strong coupling [t14/172] and at weak coupling [t16/012]. This result suggests that string theory does not admit a landscape of de Sitter vacua ruling out the popular KKLT proposal to obtain de Sitter vacua from string theory by adding anti-D3 branes to flux compactifications. We have also shown [t15/183] that for string embeddings of the standard model realized on D3-branes implying that supersymmetric extensions of the standard are basically ruled out by LHC.

Double space and generalized geometry compactifications We studied in [t15/231] how the geometry of the double space, motivated by the string winding modes and brane wrapping modes, could describe string theory compactifications on string-size tori, and reproduce the dimensionally reduced action as an Einstein-Hilbert term in the extended space [t13/055]. In [t13/043] we conjectured that the B-field dependence in the first quantum correction to the type II string effective action arising at the eight-derivative level is nearly completely captured by an introduction of a certain connection with torsion. A general formalism for incorporating the stringy corrections in the framework of generalised geometry was presented in [t14/105]. The higher-dimensional higher-derivative corrections also play an important role in derivation of new N=1 quantum corrections to four-dimensional effective actions derived in [t15/107]. A puzzling breakdown of duality with three-dimensional M-theory backgrounds points to possibility of new non-perturbative effects [t17/025].

Dipole CFTs Dipole CFTs are generalizations of conformal field theories that are non-local along a light-like direction and have non-relativistic conformal symmetry along the other directions, and they are expected to be ultraviolet complete. Until last year, only one complicated and four-dimensional example of such a theory was known. In [t17/232] we have proposed an extremely simple construction of a class of two-dimensional dipole in conformal field theory (the kind that are relevant for understanding external black holes in our world), whose properties can be studied exactly via a variety of methods, from integrability to holography to conformal perturbation theory.

Scattering Amplitudes

Amplitudes for supergravity and strings A tremendous surprise that has become incredibly apparent over the past few years is that a web of theories from the most formal to the most phenomenological all have double-copy interpretations. Using nilpotent superfields, we found that spectacularly simple models tie inflationary parameters to collider physics parameters [t15/265].

We have pursued the analysis of the double-copy in string theory to understand tree-level string-theory predictions as field-theoretic double copies [t16/201]. The most fundamental breakthrough is the application for the five loops four-graviton scattering amplitude in maximally supersymmetric supergravity, where we could double-copy loop amplitudes without putting the single-copies into a colour-dual form [t17/080] in agreement with the generalized double-copy found at tree-level. In [t17/199] and [t18/024], we have pinned down the ultraviolet behaviour of this amplitude with the goal to address the ultimate question of whether we can have point-like QFT descriptions of gravity in the four-dimensions or whether we must ultimately rely on extended structure like string-theory. This result is in line with earlier predictions and with the on-shell superspace construction made earlier in our group. In [t16/069] we have derived universal kinematic relation between one-loop integral in open string theory, generalising at one-loop order the kinematics tree-level relations.

Post-Minskowskian corrections In [t13/019] we have initiated a totally new approach to compute post-Minskowskian corrections to general relativity from quantum scattering amplitudes. We showed how to use modern unitarity technics and double-copy methods to the two-body scattering. In [t14/108] we have applied these technics to rederive the classical star light bending by the Sun and we derived a new low energy quantum gravity correction leading to a violation of the equivalence principle in an interesting new way.

Amplitudes, periods and modular forms In [t13/217, t14/015] and [t15/135] we showed that Feynman integrals are periods of mixed Hodge structures determined by the Feynman graph data. In [t13/217] we discovered the sunset Feynman integral evaluates to an elliptic dilogarithm opening a new avenue for evaluating two-loop amplitudes in quantum field theory, and in [t15/135] we proved that this integral computes the prepotential of genus 0 local Gromov-Witten, of a non-compact Calabi-Yau 3-fold with base the elliptic curve defined by the sunset graph polynomial.

In [t15/202] we have shown that the low-energy derivative expansion of the genus one string amplitude leads to a new class of modular forms that we called modular graph functions as these modular forms have only single-valued zeta in their constant Fourier coefficients.

B- Cosmology, particle and nuclear physics

IPhT has a strong activity in the fields of cosmology, particle physics, and nuclear physics. The latter subject has now become a subfield of quantum chromodynamics, since the theory of nuclear structure and low energy nuclear reactions is no longer represented at IPhT. In all of these three domains, it is important to stress the fact that our activities range from phenomenological works in direct connection with observations made at particle colliders or by in-space astronomical missions to more formal developments in quantum field theory.

Nuclear matter at high temperature and density

Quantum Chromodynamics (QCD) is the study of strong interactions. It is a vast domain of research in fundamental theoretical physics and our lab is at the forefront of a broad spectrum of activities in QCD with several major contributions over the reporting period. An area of QCD actively studied in our lab is the physics of nuclear matter in extreme conditions, mostly in heavy ion collisions. High-energy heavy-ion collisions at RHIC and at the LHC produce a quark-gluon plasma (QGP) similar to what was created shortly after the Big Bang. We study this fundamental, but complex, QCD system at various stages of its evolution.

Flow, anisotropies and fluctuations In many respects, the QGP behaves like a perfect fluid, as can be shown by the study of azimuthal particle distributions based on a hydrodynamical description. Recently, we have put a lot of effort into the description of anisotropies based on the initial shape fluctuations [t14/232] and the corresponding hydrodynamical response of the system to those fluctuations [t15/015]. Amongst our important findings, we have highlighted universal non-Gaussian fluctuations in small systems [t13/287] — the best signature of collectivity in small systems to-date — and in large systems [t16/072]. The predictions we have obtained have then been successfully compared to measurements by the CMS and Alice collaborations at the LHC.

Flow from microscopic dynamics Understanding in terms of fundamental QCD degrees of freedom why the QGP is interacting sufficiently strongly to sustain hydrodynamical flow despite a rapid expansion remains an outstanding question. We have made substantial progress on this question, first by setting up the formalism and obtaining numerical results from a first-principles NLO-resummed calculation [t13/190, t13/191], then by showing in kinetic theory [t15/123] that purely classical approximations fail to correctly describe the expansion of the system. We have also discussed [t16/228, t16/229] the relative importance of elastic and inelastic collisions for the thermalisation of the QGP, and used simple moments of the distribution functions to address the onset of hydrodynamical evolution [t17/093]. On a related note, we have also studied the correlations between local observables in a system subject to instabilities that lead to strong fields [t17/083].

In-medium modification of probes Another important approach to extract properties of the QGP is to study how high-energy probes such as jets or heavy quarkonia are modified by their interaction with the QGP. Over the reporting period, we have studied the formation and dissociation of heavy-quark bound states in the QGP, based on a generalised Langevin equation, first for an Abelian plasma [t15/075] then extending the approach to QCD [t17/190]. We have extensively studied how jets propagate through the QGP, reaching important results for each of the two main sources of gluon radiation in the QGP. First, we have shown that the radiation induced by collisions off the QGP can be described by a classical stochastic process (yielding to wave turbulence), [t13/038, t15/073]. More recently, we have provided the first description of vacuum-like emissions in the QGP showing that they factorise from the medium-induced emissions [t18/016].

Gluon saturation Another longstanding activity of the lab on fundamental properties of QCD is the question of the high-energy limit of QCD and gluon saturation phenomena. Evolution equations towards high energy are known up to next-to-leading order (NLO) accuracy. Several pathologies appear at NLO and our main activity over the reporting period has been to cure these pathologies. In [t15/271], we identified the source of the instability of the NLO evolution equation and cured this problem via an all-order resummation of the leading perturbative corrections. Then, in [t16/243], we reformulated the high-energy factorisation so as to guarantee a positive-defined production cross-sections.

Nuclear matter at high density We have also studied nuclear matter at high density such as in neutron stars. To that effect, we have introduced a new effective field theory approach whereby quark-gluon degrees of freedom in QCD are traded in for topology [t15/270, t17/043, t17/114], showing the possible onset of strong-coupled quark-gluon degrees of freedom at high baryonic density.

Amplitudes for the LHC

On a different topic, we are working on the development of new techniques to compute scattering amplitudes and their properties. The field of "amplitudes" has seen a tremendous progress recently, both in terms of a deep understanding of the analytic structure of amplitudes, and in terms of precision for the LHC. We have contributed several key results over the past few years. On the more formal side (see also the mathematical physics section), we have introduced a new approach to compute energy-energy correlations in gauge theories, bypassing the explicit use of scattering amplitudes [t13/264]. In an effort to reach an increased precision, we have extended the calculation of the angle-dependent cusp anomalous dimension at three loops [t15/174]. We have also made an important progress towards NNLO with extensions of the generalised unitarity technique to one particular type of two-loop integral [t13/204]. On a more phenomenological side, we have introduced a new constructive approach to obtain integration-by-parts (IBP) identities, simplifying the calculation of large numbers of Feynman integrals [t18/046]. Finally, as part of the BlackHat collaboration (providing NLO processes for the LHC), we have computed the production of a W boson associated with 5 jets [t13/114]. This calculation uses a new, flexible, n-tuple format [t13/228].

Jet substructure

The last field of QCD that we have been working on is jet substructure, the study of the internal dynamics of jets. This is an increasingly important field at the LHC for both measurements and searches. We have developed a first-principles approach in QCD to understanding jet substructure. Our most representative contribution is probably the introduction and study of the Soft Drop tool [t14/146], now used routinely at the LHC and for which we recently started making precision calculations. Using our first-principles approach, we have introduced new tools, like the "dichroic" ratios [t16/180], with improved performance for tagging boosted bosons and hence for possible new physics discoveries. On a related topic, we have introduced an approach to resum logarithms of the jet radius for a wide series of observables [t15/082].

Physics beyond the Standard Model

The research activities in particle physics beyond the Standard Model cover a wide range of topics, including Higgs and collider physics, dark matter phenomenology, neutrino physics and baryogenesis, Grand Unification, as well as more theoretical work on effective field theories and their applications to particle physics and quantum gravity.

Constraints on effective theories Powerful non-perturbative constraints on effective field theories (known as "positivity bounds") can be obtained from the requirement of unitarity, analyticity and crossing symmetry of the scattering amplitudes. In [t15/161], we derived bounds on the Wilson coefficients of the operators that modify Einstein gravity, under the assumption that the ultraviolet completion is causal, unitary and Lorentz invariant (like e.g. string theory). In [t17/151], we focused on infrared modifications of gravity such as ghost-free massive gravity and the galileon theory. The combination of our theoretical bounds with experimental constraints on the graviton mass implies that ghost-free massive gravity is ruled out as a theory capable of describing the observed gravitational phenomena.

BSM modelling In [t17/014], we studied the effective theory of a generic class of hidden sectors where supersymmetry is broken together with an approximate R-symmetry at low energy. The light spectrum contains the gravitino and the pseudo-Goldstone boson of the R-symmetry, the R-axion. We derived new model-independent constraints on the R-axion decay constant for R-axion masses ranging from GeV to TeV, which are of relevance for hadron and lepton colliders and for B-factories. In [t14/025], we presented an overview of composite Higgs models (including little Higgs, holographic composite Higgs, twin Higgs and dilatonic Higgs models) in light of the discovery of the Higgs boson. We reviewed the current experimental status of these models (electroweak precision tests, flavour constraints and direct search bounds).

Dark Matter Although dark matter constitutes 26% of the total matter-energy budget of the Universe, its nature is still unkown. There are strong hints that it might be a new fundamental particle, not yet discovered. Our research activities in the domain of particle dark matter are directly related to the experimental search strategies: direct detection (nuclear recoils in ultrapure experiments), indirect detection (excesses in cosmic rays resulting from the annihilations of dark matter particles) and production at colliders. In [t15/081] we showed that, contrary to the claim of the AMS collaboration, there is no clear excess in the antiproton flux measured by AMS itself that can be attributed to annihilations of dark matter particles. In Ref. [t15/130], we computed the gamma ray signals from dark matter annihilations in a specific model (the so-called Minimal Dark Matter model proposed by us in 2006) and confronted it with data. Due to the uncertainty on the dark matter profile in the Galactic center, no definite conclusion about the viability of this model could be reached. In [t15/165] we investigated the possibility of explaining the long-standing excess of GeV gamma rays from the Galactic center in terms of ordinary cosmic ray sources and standard steady-state diffusion, rather than dark matter annihilations. The conclusion is that both explanations provide equally good fits to the data. In [t13/040], the numerical fluxes of neutrinos coming from the annihilations of dark matter particles in the center of the Sun were computed and made available to the community. In [t13/022], we provided a self-contained set of numerical tools to derive, in a framework based on non-relativistic operators, bounds from the main current direct detection experiments on virtually any model of dark matter elastically scattering on nuclei.

Matter-antimatter asymmetry One of the big unsolved problems of particle physics and cosmology is the origin of the matter-antimatter asymmetry of the Universe. An attractive possibility is to generate it through the decays of heavy Majorana neutrinos - a mechanism known as leptogenesis. In [t15/025] we studied a variant involving a scalar electroweak triplet instead of Majorana neutrinos. We presented a flavour-covariant formalism taking into account the effects of the different lepton flavours in a consistent way, and investigated numerically their impact on the generated baryon asymmetry, which was found to be significant. In [t16/030] we investigated the compatibility with experimental data of the minimal renormalizable supersymmetric Grand Unified model based on the SU(5) gauge group. We found that the only regions of the parameter space surviving the constraints from proton decay, the Higgs mass, quark and charged lepton masses, gauge coupling unification and perturbativity feature very heavy superpartners, typically in the 100 to 10^4 TeV range, and that the electroweak vacuum is metastable.

Cosmology and gravity

Two important ESA missions are shaping the future of cosmology and astrophysics. One is Euclid, a space telescope designed to measure the galaxy shapes and positions up to high redshift. The correct interpretation of its data will test the seeds of primordial cosmological perturbations and will establish the impact of dark components–such as massive neutrinos and dark matter–and the presence of modifications of gravity, on the dynamics of the large-scale structure. The other mission is LISA, a space-based interferometer designed to detect gravitational waves produced by coalescing super massive black holes binaries or strong first-order phase transitions in the early universe.

In this context, a major part of our activity in cosmology and gravity focused on theoretical aspects relevant for these missions: the study of the dynamics of the large-scale structure (LSS) of the universe, the modelling and parametrization of modified gravity theories and the predictions of gravitational waves spectra emitted at early times or from compact binary inspirals.

Large scale structures A large part of the information in the LSS resides on short scales, where density perturbations become large and enter the nonlinear regime. This is studied with N-body simulations, which have been used to reconstruct the response function measuring the impact of the small-scales on the large-scale physics [t13/385]. But to treat the nonlinear regime, we have developed several complementary techniques that rely on well-understood mathematical constructions. One is based on the large deviation principle [t15/235]. Other approaches, developed for standard gravity and applied to make predictions in modified gravity scenarios, use standard perturbation theory on large scales and regularize the UV regime either with a phenomenological halo model [t13/135, t13/136] or with semi-analytic resummation techniques [t14/244].

Moreover, we have identified a way to sort out the information content coming from different scales in weak lensing observables [t13/292]. Finally, we have constructed relations between correlation functions of the cosmic fields–such as the dark matter density contrast and velocity–that are exact and non-perturbative for one of the wave-modes much smaller than the others [t14/170, t16/078]. These relations can be used to test the consistency of the standard model or, if violated, to detect primordial non-Gaussianities or fifth forces.

Modified gravity The major goal of Euclid is to shed light on the origin of the cosmic acceleration and test general relativity on cosmological scales. At IPhT we have developed new modified gravity theories and studied their phenomenological consequences. One way to modify gravity is to weaken it on large scales, by giving the graviton a tiny mass. We have studied the cosmology of the most viable realization of this theory [t16/225], called bigravity, which involves two dynamical metrics coupled via a potential term designed to avoid instabilities.

Another way to modify gravity is to add a scalar interaction. The fifth force exchanged by this scalar must be screened on Solar System scales by nonlinear self-interactions. We have studied the cosmological effects of modified gravity models with screening [t13/136, t14/244] and, in particular, the effects associated to the so-called "k-mouflage" screening [t15/054, t16/079], as well as its quantum stability. The need for screening has pushed to consider higher-derivative interactions and higher-order equations of motion. In [t14/164], we have shown that scalar-tensor theories with equations of motion higher than second are not necessarily unstable, as previously believed, opening up a new class of theories. Finally, due to the large number of models of modified gravity in the literature, we have developed a unifying framework [t14/305] to compare them with data in terms of a minimal number of parameters, now adopted by most collaborations to parametrize deviation from general relativity on large scales.

Gravitational waves The recent detection of gravitational waves by the LIGO/Virgo collaboration has opened a new window on the Universe. Although undetectable by current or planned interferometers, the search for the relic gravitational wave background produced by inflation has become the major activity of many cosmic microwave background polarization experiments. In [t14/163], we have shown that the inflationary predictions are completely robust, i.e. it is not possible to alter them by modifying the speed of propagation of tensors during inflation, as can be done for the scalar sector.

The simultaneous observation of gravitational waves and gamma ray bursts from the merger of two neutron stars, implying that gravity travels at the same speed as light, had dramatic consequences on modified gravity theories. We have shown that this observation strongly constrain the matter coupling in bigravity theories [t18/031], while it rules out a large portion of the parameter space in scalar-tensor theories [t17/206]. For both these theories, we have derived the most general classes that leave the speed of gravity unaffected and we have explored their consequences for structure formation.

LISA will observe at much smaller frequencies than LIGO/Virgo. Closely related to its main goals, at IPhT we have investigated how its various configurations can probe the cosmic background expansion using gravitational wave standard sirens [t16/236] and detect strong first-order cosmological phase transitions in the early universe, in various scenarios motivated by physics beyond the standard model [t15/251]. These documents have crucially guided the ESA decisions on the final instrumental configurations. We have also estimated how LISA can constrain dark energy models and detect the peculiar acceleration of black hole binaries, which can be used to infer the binary environment and formation process.

C- Statistical and condensed matter physics

Our activities in statistical and condensed matter physics are divided into three groups: Non equilibrium statistical physics, disordered systems and condensed matter physics. One should note that in the last 2013 report they were grouped in a slightly different way. This does not reflect a drastic change in the activities of this theme but evolutions in subjects and perspectives. These three subgroups are discussed and detailled below. Let us stress that in both groups, the contact with experimental groups is more and more important. In particular contacts and collaborations on some specific problems with teams of the life science institutes of CEA/DRF are under developments. This is a new and promising trend.

Non-equilibrium physics

Many natural systems are far from equilibrium, either because having started from a non-typical initial state, they have not yet thermalized, or because they are restlessly driven out of equilibrium through exchanges of matter, energy or information with their surroundings resulting in currents that break time-reversal invariance. In such situations, the principles of equilibrium statistical mechanics do not apply: the theoretical understanding of the dynamical behaviour of many-body systems far from thermal equilibrium is one of the major challenges of contemporary statistical physics and a common trend of many studies carried out in our group.

Current works in this field follow two complementary strategies: one can explore universal features of non-equilibrium systems from a conceptual point of view; or, study some simplified models, classical or quantum, and derive some general understanding. In particular, rigorous studies of stochastic interacting particle processes are a long standing specialty of our group. This important part of our activity yields universal methods that can be applied to investigate the complex dynamical behaviour of biophysical matter (RNA, proteins and viruses) or of emergent artificial systems (communication networks, urban sprawl and cities).

Fluctuation theorems Fluctuation relations, now currently used in experimental settings, establish structural properties of the probability distribution of some physical observable (say work) at a fixed time or in the long time limit. Our contribution [t14/038] was seminal in a dual approach: we studied the distribution of the time required to produce a given amount of this physical observable and derived a new kind of fluctuation relation that fits well in a number of experimental settings and highlights the crucial importance of the notion of affinity in thermodynamic cycles. For quantum systems, the field theoretical transformation associated with time-reversal symmetry was identified in [t17/096]: it plays an important role in deriving quantum fluctuation theorems.

Out-of-equilibrium phase diagrams Non-equilibrium systems can exhibit complex phase diagrams even in low dimensions and phase-coexistence that violate the classical laws of thermodynamics. For example, in [t17/070], we perform a quantitative analysis of generic bistability in two-dimensional totally asymmetric kinetic Ising model. In [t17/048], finite-time corrections of the coarsening regime of the Zero-Range Process are obtained, and in [t15/234] a complete classification of integrable open boundaries asymmetric simple exclusion processes with two species of particles is established. The exact distribution of a tracer particle in the exclusion process, valid for all times, is found in [t17/029] in terms of a Fredholm determinant.

Dynamics and transport Quantum non equilibrium dynamics exhibit qualitatively different properties from those of classical ones, that can be probed through the study of quantum walks. As a quantum walker propagates ballistically and its wave-function exhibits sharp ballistic fronts, it can easily avoid a static trap, so that it survives forever with non-zero probability (at variance with a classical random walker). In the presence of a finite concentration of identical randomly placed traps, the typical survival probability of a quantum walker falls off as a stretched exponential for long times, with an exponent different from the classical one [t13/265]. Bound states formed by two or more interacting quantum walkers, either fermionic or bosonic, also spread ballistically with many internal fronts in the center-of-mass coordinate, besides the two extremal ones [t15/129]. For several non-interacting quantum walkers, the return probability to their global initial state falls off as a power law in time [t17/159]. In [t15/182], we propose a quantitative tool characterizing the degree of equilibration of the bound states and apply it to a panoply of other situations, including a particle in a one-dimensional disordered potential or in a constant electric field, and an arbitrary quantum spin in a tilted magnetic field.

Exact studies of model systems often rely on sophisticated theoretical techniques (algebraic integrability, field theory, random matrices). It is therefore natural that some of our works have a strong mathematical flavour, such as the study of record statistics of strongly correlated time series generated by a random walk or a Lévy flight on a line [t17/049]. In the context of random matrices, we have solved completely the problem of Lévy (or heavy tailed) matrices; in particular we have worked out the level statistics, which is also relevant for current questions on Many Body Localization [t15/157] and have studied the localization transition and the multifractality of eigenvectors in the localized phase through a strong disorder perturbative expansion [t16/088].

The continuous limit of driven diffusive systems yields non-linear hydrodynamic equations for the density of the current, which are at the heart of macroscopic fluctuation theory (MFT), a promising framework for analyzing systems far from equilibrium. In [t16/191], a variational calculation of the transport coefficients of the MFT equations for non-equilibrium lattice gases was carried out. In [t14/098], the MFT, interpreted as a classical field theory, was used to calculate the anomalous diffusion of a tracer in single file transport and the hydrodynamic profile of the interface perturbed by the tracer.

Applications to biophysics Non-equilibrium transition paths between different states of a complex system can be modeled by a constrained Langevin equation. An exact mathematical formulation of this dynamics was found and applied to sampling the paths between folded and unfolded states of a protein [t16/214]. It was also applied in [t17/215] to transitions amongst different knotted states in DNA, in presence of a topoisomerase: we have proved, in particular, that the erasing of a knot can require a complicated dynamics, involving transitory knotted configurations of a complexity higher than the initial one. Transcription factors generate loops on the DNA chain, drawing closer co-regulated genes, that are located far apart along the DNA chain. By studying the phase diagram of a semi-flexible polymer in presence of binding proteins, we have shown that transcription factories appear and have studied their structure [t15/207].

DNA molecules are knotted and so are roughly 3% of proteins; we have performed a statistical study of known RNA structures in data bases and have concluded that RNA strands are not knotted, a fact that has far reaching biological and evolutionary implications [t14/263]. We have explained the different RNA profiles observed inside viral shells by studying the impact of base pairing on the conformations of RNA and showing that it undergoes a swollen coil to globule continuous transition as a function of the strength of the pairing interaction [t17/214].

Amyloid fibrils are misfolded aggregates of proteins that are responsible of major diseases including diabetes, Alzheimer and Parkinson. Using CreateFibril, a computational framework we developed, we explore the stability of fibrils and demonstrate that nucleation of stable aggregates becomes energetically favorable beyond a certain size limit [t13/160]. Using field-theoretical techniques, we have revisited the Onsager-Samaras theory of electrolytes surface tension for ions located at the interface of two media with different dielectric constants (such as water and air) and have calculated precisely the shape of the ionic density profile at the vicinity of the interface [t16/215].

The form of a macromolecule determines its function: in [t16/220] we explain how Small Angle X-Ray Scattering (SAXS) curves can be used to determine a whole family of structural invariant, that go far beyond the radius of gyration of the molecule and lead to the full pair distance distribution function. This allows us to define a metric between shapes and paves the way for designing new shape reconstruction strategies from the SAXS experimental data.

Spatial networks Spatial networks that describe complex systems under the form of networks where nodes and edges are embedded in space [t18/076]. Transportation and mobility networks, Internet, mobile phone networks, power grids, social and contact networks, neural networks, are all examples where space is relevant and where topology alone does not contain all the information. An important consequence of space on networks is that there is a cost [t13/184] associated to the length of edges which in turn has dramatic effects on the topological structure of these networks [t15/031]. Our main goal is to understand and model the structure, formation and evolution of these spatial networks [t15/031] with potential applications in different fields ranging from geography, urbanism, to epidemiology and the neurosciences.

The recent availability of urban data opens the exciting possibility of a new "Science of Cities" [t16/240] , with the aim of understanding and modeling phenomena taking place in the city. Urban morphology and morphogenesis, activity and residence location choice, urban sprawl and the evolution of urban networks, are some of the important processes that we study [t13/353, t13/198, t17/161]. This effort towards understanding an object as complex as a city is necessarily interdisciplinary: we need to build up on early studies in quantitative geography and spatial economics, on the knowledge of architects, urbanists and urban sociologists, and on the tools of geomatics together with modeling approaches coming from statistical physics [t18/075].

Disordered systems

Another class of problems that have challenging properties from the statistical physics point of view are disordered systems, in particular glasses and spin glasses. Moreover many problems of interest in other disciplines such as statistical inference, optimization or machine learning can be formulated as disordered systems and the methodology developed in statistical physics of disordered systems thus leads to remarkable results also in those disciplines.

In IPhT we traditionally focus on understanding the theory and properties of super-cooled liquids and structural glasses. These topics were studied in statistical physics for many years, yet the last couple of years brought new enlightening results and development into which researcher in IPhT contributed significantly.

Glassy transition In particular in [t14/318] we did a complete field theoretical analysis of the cooperative regions responsible for slow dynamics. By combining theory and experiments we have shown for the first time the growth of static amorphous order approaching the glass transition in [t16/119]. We have developed the analytical solution of structural glass models, such as hard and soft spheres in the infinite dimensional limit [t14/313]. The main outcome of this mean field analysis has been that within the glass phase a new phase transition may arise, the Gardner transition, and we have investigated the consequences of that. In particular we have shown that this is responsible of the criticality emerging in the statistical properties of amorphous jammed packings of hard spheres and we have computed the critical exponents characterizing them [t14/313]. Furthermore we have shown that it may be an explanation of the abundance of soft vibrational modes found in glasses [t15/255]. We have used the infinite dimensional solution of structural glass models to construct a theory of the rheology of amorphous solids through which we have been able to give a a set of prediction ranging from jamming by shear in hard spheres, to the properties of the yielding transition [t16/178]. In [t16/141] we showed that standard elasticity theory breaks down when amorphous solids undergo below the Gardner transition, thus unveiling that amorphous solids possibly change nature at at low temperature and high pressure. Finally we developed a new approach that enable us to take into account non-perturbative finite dimensional fluctuations which are missed by mean-field theory were made in [t16/208] and [t16/120].

Spin glasses In the field of spin glasses we investigated some of the deep long-standing questions. It has been argued that, due to chaotic size dependence, a disordered system Gibbs state may not converge to an infinite volume state in the thermodynamic limit, but rather sample a distribution of states, the so called metastate. In the case of the low dimensional Edwards-Anderson model this leads to a variant of Parisi mean field picture, where each state drawn from the metastate has indeed all the features of the mean field RSB solution, whereas averaging over the metastate washes out most structure, in agreement with rigorous results of Newman and Stein. In [t17/068] we present a numerical construction of the metastate for the d=3 Edwards-Anderson model, using the original definition of the metastate due to Aizenman and Wehr. Our results indicate that the Edwards-Anderson metastate is dispersed, namely is made of many states, in agreement with the mean field picture and in contradiction with the so-called droplet picture. In [t14/109] we investigated the hierarchy of dynamical barriers in long-ranged spin-glasses. The related real-space renormalization procedure represents a simple explicit example of the droplet scaling theory, where the convergence towards local equilibrium on larger and larger scales is governed by a strong hierarchy of activated dynamical processes, with valleys within valleys.

Phase transitions in computational problems and algorithms Analytical methods originating in statistical physics of disordered systems are being successfully applied to problems outside of physics. One of the interesting endeavours is to in a certain sense translate the analysis calculations (often averaged over disorder) into practicable algorithms for the task under investigation. Our activities in this direction were reviewed in [t16/134]. In a series of works [t17/011, t17/108] we described quantitatively phase transitions and their computational consequences for a generic class of problems called low-rank matrix (or tensor) estimation, that is in physics-terms related to mean-field spin glasses with vectorial spins and quenched disorder being correlated with one special configuration of spins. Particularly interested is the precisely location of a so-called hard phase where inference is possible information-theoretically but we do not know of an efficient algorithm able to achieve it. While the methods used traditionally to study such a system are not rigorous, we made a considerable progress in their rigorous vindication in the problem of low-rank matrix estimation in a series of mathematically rigorous works [t16/125, t16/175, t17/108].

Insights gained in the analysis of associated phase transitions naturally leads to developments of new algorithms. Among the most significant ones developed recently in IPhT is the spectral method based on the so-called non-bactracking matrix [t13/152] that has been used for sparsely-related data clustering. An extension of the algorithms [t14/297] is based on a Hessian of the Bethe free energy. An algorithmic application of the non-backtracking matrix to the well-studied problem of percolation on graphs was developed in [t14/298]. Among other notable applications of statistical physics of disordered systems to optimization problems developed recently in IPhT is the work on finding origin of an epidemic spreading [t13/156] or dismantling of random graphs, i.e. removal of minimal number of nodes that cause breakdown of the giant component, both using message passing algorithms.

Condensed matter theory

Condensed-matter occupies a large place in physics, and the theoretical concepts developed for these problems have often had an impact in other fields of physics. Likewise, the research carried out at the IPhT on condensed-matter systems has been tightly connected to other fields of theoretical physics, such as statistical physics, field theory, or integrable systems. In the last few years we focused on the following directions: topological states of matter, many-body problems, systems far from equilibrium, and disordered systems.

Quantum phase transitions Quantum phases of matter with topological properties – subject of the 2016 Nobel Prize - represent a very active topic worldwide. Among these, systems supporting Majorana modes are actively studied, in part because they could be used in future device for quantum information processing. In [t17/169] we proposed a new order parameter, the Majorana polarization (MP), which captures locally the formation of a Majorana state. We showed that the MP is needed to characterize Majorana states, particularly in finite-size systems. Motivated by the fact that a p-wave superconductors can support Majorana modes, the response of a superconductor (of p-wave type, or with spin-orbit coupling) to magnetic impurities was worked out in [t16/102]. The resulting Friedel oscillations can be used to test the nature of the SC order parameter, or to evaluate the spin-orbit coupling amplitude [t16/218]. The Friedel oscillations in some functionalized graphene systems were also studied [t16/101].

High critical T superconductors Quantum many-body systems where the interactions between the particles play a central role, where non-perturbative (or beyond mean-field) effects need to be taken into account, are challenging problems. A prominent example is that of high-temperature (HT) cuprate superconductors. They have been studied theoretically and experimentally for several decades, but some key questions remain unsolved. This is the case of the pseudo-gap phase of the cuprate, which nature is yet to be understood. In [t13/129] a novel field-theory description (non-linear sigma model), constructed from degrees of freedom living in the vicinity of specific points (hot spots) of the Fermi surface, and from an SU(2) symmetry relating two apparently unrelated types of order (d-wave superconductivity and a spatial charge modulation) was proposed. This model was then refined to describe some aspects of the cuprate phenomenology, including in the pseudo-gap part of their phase diagram ([t15/241] and [t15/242]), or in presence of an external magnetic field [t17/216].

The HT superconductivity has also been studied by designing a controlled expansion to solve the doped Hubbard model – a classic lattice model of interacting electrons. An achievement was the introduction of a method, dubbed Triply Irreducible Local Expansion (TRILEX) [t17/104, t17/105], [t16/066, t15/066, t15/245]. Based on a local approximation of the effective interaction vertex between electrons and any bosonic fluctuation, it maps the lattice problem to a self-consistent quantum impurity problem. Although similar to DMFT (Dynamical Mean Field Theory), the self-consistency is here made on the vertex function, not the self-energy. Remarkably, a single-site implementation of TRILEX already reproduces the dome shape of the superconducting region in the temperature–vs-doping phase diagram of the Hubbard model.

Out-of-equilibrium systems The field of quantum systems which are far from equilibrium has developed rapidly in the last decade, in part thanks to the advances on the experimental side (cold atoms, artificial light-matter systems, etc.). One way to set a system out-of-equilibrium is to perform a quantum quench. There, an isolated system is prepared in some simple state at time $t = 0$ (not an eigenstate of the Hamiltonian) and then it evolves unitarily for $t > 0$. Such protocols allow to address important questions about the equilibration or transport in isolated quantum systems, and to discuss the role played by interactions. In [t13/325] and [t17/205] we focused on inhomogeneous quenches in spin-1/2 chains, where the two halves (left and right) of the system have different magnetizations at t=0. By comparing the simulation results to various analytical approaches, a number of questions were addressed: lattice effects (deviations from the continuum limit), transport and current-voltage curves beyond the linear-response regime, entanglement entropy, and the possibility of a diffusive behavior (as opposed to ballistic) for the Heisenberg model.

We have also introduced a Quantum Monte Carlo (QMC) method for interacting systems far from equilibrium, the first diagrammatic QMC using an explicit sum of the Feynman diagrams in terms of an exponential number of determinants. Physical quantities are expanded in powers of the interaction, at any finite time or in the steady-state limit. Here the sign problem of QMC reduces to a mathematical question of reconstructing the physical results as analytical functions of the coupling constant, from the perturbative series, e.g. using conformal transformation in the complex plane of the coupling constant, as demonstrated in the case of a Kondo model with two leads [t15/064].

In open quantum systems, interesting non-thermal stationary states can appear when dissipation mechanisms compete with the coherent dynamics, and, as was shown in a Rabi-Hubbard model [t15/033], novel classes of quantum phase transitions can appear. The interplay of dissipation and disorder was also studied in the framework of disordered spin chains obeying a Lindblad dynamics [t17/024, t17/023].

Rich nonequilibrium phenomena also occur in models which are periodically driven. We may cite in particular some results obtained in presence of strong disorder using a real-space renormalization method, leading to some "Floquet Localized phases" [t17/022]. In another work, a Fermi-Hubbard model with a time-periodic modulation of the interaction was studied using a numerical approach (nonequilibrium DMFT). It revealed complex pathways to thermalization in presence of strong interactions, with exponentially long time scales, and sharp transitions between different dynamical regimes [t18/020].

Many-body localization Last but not least, a new phase of matter has triggered a huge activity I the last few years. Dubbed many-body localization, it is the interacting counter part of the (single-particle) Anderson localization. Such disordered systems display many interesting anomalous properties, like the absence of thermalization. We have made some contributions to this new field, including studies of the emerging local integrals of motion [t16/019] [t18/014], the slow dynamics for a model on the Bethe Lattice [t15/157] or a renormalization-group like flow of the Hamiltonian couplings [t17/218].

Highlights

Jumps and spikes in quantum trajectories

Abstract: Quantum technologies, involving the control of imperfectly isolated quantum systems, open great hopes. Deep questions, foreseen by the fathers of quantum mechanics, are now subject to experiments. Manipulating small quantum systems is a clue to open technology locks. Observing jumps was a landmark in the field, but theory predicts also more fragile excitations, spikes. Their description involves elaborate mathematics, and could lead to new room for a delicate control of the quantum world.

Recent years have seen a revolution in the manipulation of simple quantum systems, following impressive advances in high-speed electronics and low-temperature physics. The gedanken experiments of early quantum mechanics can now be performed in laboratories.

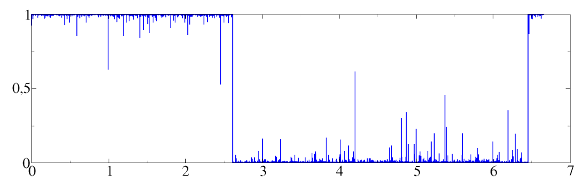
These experiments involve indirect measurements: a probe couples to the system for some time, entangles with it, and is then subjected to a standard quantum measurement, with a random back-reaction on the system. Then another probe (often independent of the previous one in practice) is coupled to the system and the protocol goes on.

In cavity quantum electrodynamics (QED), the system is made of photons and the probes are atoms flying through the cavity where their coupling to the magnetic field depends on the number of photons inside. Cavity QED tests the system at discrete times, but experiments in circuit QED (beautiful ones are performed at SPEC nearby IPhT) are continuous time analogs. Discrete and continuous time protocols are called monitoring.

Pointer states of the system are those preserved by the interaction with, and the measurement of, the probes (turning of by thought the intrinsic time evolution of the system). When they form an orthogonal basis, the measurement is called quantum non-demolition (QND).

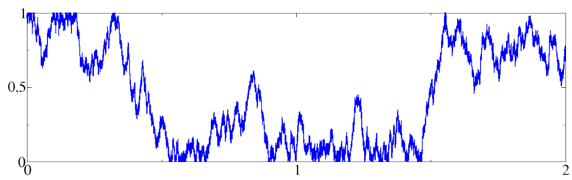
Experiments have direct access only to the probe measurement readings, but quantum trajectories are a most useful tool to analyze them. These are the trajectories of the density matrix of the system as it changes both under (deterministic, linear) conservative (Hamiltonian) or dissipative (Lindbladian) dynamics and (random, nonlinear) monitoring effects.

From a theory viewpoint, many experiments are well modeled by a Markovian dynamics, and by stochastic differential equations (SDEs) with additive noise for the measurements and multiplicative noise for the quantum trajectory.



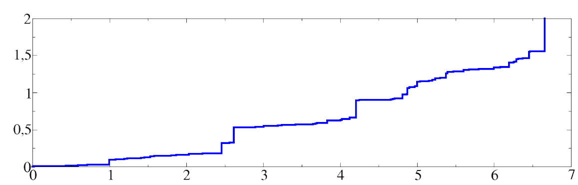
Jumps and spikes in a quantum trajectory.

Our results concentrate on the large noise regime and can be summarized as follows: *a*) We give a quantitative version of the Zeno effect, i.e. characterize fully the regime of parameters where the deterministic evolution competes with large noisy effects. *b*) We show that in this regime trajectories are intermittent: the system is mostly frozen in pointer states due to strong noise, but exhibits bursts of activity kicked by the deterministic evolution. This results in jumps from one pointer state to another, or in excitations above a given pointer state, spikes. *c*) For non demolition measurements in this limit, the correlations functions (for a finite number of times) in the system are those of a Markov chain on pointer states, with a transition kernel for which we give a general formula. *d*) Spikes manifest themselves only in more global features of the trajectories and lead to anomalous behaviors. We have a complete description when the problem reduces to a single SDE, for instance in the central case when the system is a single Qubit. We developed original mathematical techniques to deal with strong noise limits of certain SDEs, leading to describe spikes as (variants of) Poisson processes. *e*) These processes are shown to be functions of a reflected Brownian motion parameterized by linear combinations of the the local time it spends in pointer states. The clue for this equivalence is to use an effective time: the standard clock ticks at the passage of probes, but it is the magnitude of the (random) effect of the probes on the system that triggers effective clock ticks.



The quantum trajectory unfolded.

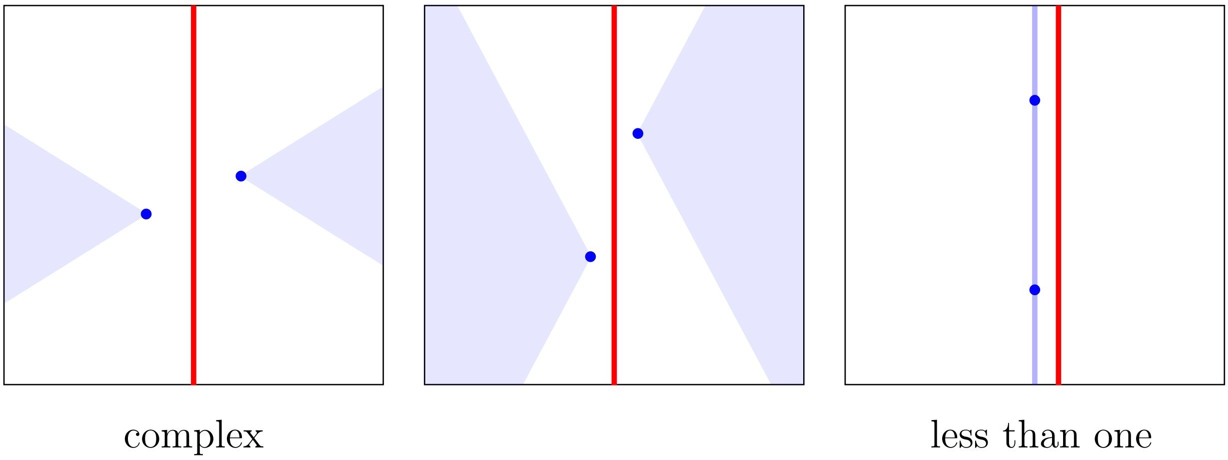
Using an effective time to unfold other intermittent signals could have applications for many phenomena like turbulence or seismology. This promising approach remains conjectural for experimental and theoretical reasons. Staying in the realm of quantum systems, an understanding of spikes for several degrees of freedom is is needed. More generally, quantum mechanical stochasticity in more complicated systems (spin chains are relevant models) deserves a detailed study, with applications to transport for instance.



Effective time versus real time.

Liouville theory with a central charge less than one

Abstract: Liouville theory had been solved for most complex values of its central charge. However, the case of central charges less than one remained problematic because of singularities of correlation functions. The path-integral approach had been unhelpful if not misleading to address the issue. We used the conformal bootstrap approach instead, and regularized the singularities. Liouville theory with a central charge less than one is now solved, paving the way to applications to statistical physics.



Liouville theory is the simplest nontrivial two-dimensional conformal field theory with a continuous spectrum. It appears in various contexts, including quantum gravity, statistical physics, string theory, and enumerative geometry.

Analytic continuation of Liouville theory In two dimensions, conformal symmetry is described by the Virasoro algebra, which depends on a number called the central charge. In theories such as the critical Ising model, the central charge takes fixed values. In Liouville theory however, the central charge is a parameter. Liouville theory was originally defined for central charges larger than 25 using a path-integral approach that is not manifestly well-defined for other central charges. It was then realized that the theory could be analytically continued to all complex central charges, except the values less than one. Unfortunately, these are also the most relevant values in statistical physics applications.

In order to understand how Liouville theory depends on the central charge, the original path-integral approach is difficult: it took a long work by Harlow, Maltz and Witten in 2011 to get some understanding of the analytic continuation of the path integral. In the conformal bootstrap approach however, the analytic continuation is easier. Already in 2005, Al. Zamolodchikov understood that the continuation was possible except for central charges less than one, and computed three-point structure constants for all central charges.

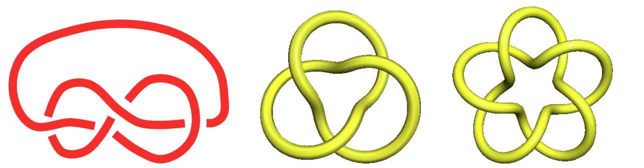
The puzzle of the spectrum It remained to determine the spectrum of Liouville theory with a central charge less than one, and to prove crossing symmetry. (In the conformal bootstrap approach, crossing symmetry is equivalent to the existence of the theory.) The answer that we found [t15/048], is that the spectrum is formally the same for all central charges. There may be two reasons why such a simple answer was not found before. First, in 2003, motivated by string theory applications, Strominger and Takanagi argued that the theory was time-like, i.e. that its spectrum had unbounded negative energies. This notion was natural in the path-integral approach, and gave rise to "time-like Liouville theory", a theory that is now known to grossly violate crossing symmetry. Second, the positive energies that appear in the spectrum of Liouville theory for all central charges, happen to coincide with singularities of correlation functions precisely if the central charge is less than one.

We have found that this technical problem is solved by an appropriate regularization. In the figures, we have represented the spectrum of Liouville theory as a red vertical line, and the singularities as two blue cones. For generic complex central charges, the singularities stay well clear of the spectrum. As the central charge approaches a value that is less than one, the cones widen, until they become vertical lines and coincide with the spectrum. The regularization is to shift the spectrum by a small amount (here, to the right) if the central charge is less than one. The failure of the analytic continuation for central charges less than one is now explained by one cone of singularities having to cross the spectrum.

Outlook Liouville theory with a central charge less than one can now be considered as solved. This paves the way to applications to statistical physics. We have already made further progress in that direction by showing in [t15/260] that the theory has a microscopic interpretation in terms of loop models.

Asymptotics of Knots and random matrices

Abstract: There are hard conjectures in mathematics about the asymptotic expansions of knot invariants (Jones polynomial and its generalizations). The topological recursion (recursion satisfied by random matrix correlation functions in the large size limit) helps to provide some answers.



Left: The figure 8 knot. Middle: Torus knot (3,2). Right: Torus knot (5,2).

To define a knot invariant, consider the Chern-Simons gauge field theory in the 3d space (3-sphere S^3), and compute a Wilson loop: the trace, in a representation R of the (time–ordered) exponential of the integral of the gauge field along the knot. With the group $SU(2)$ and fundamental representation this gives the Jones polynomial, with another representation this yields the colored Jones polynomial, and with the group $SU(n)$ this is the HOMFLY polyomial $J_{n,R}(q)$.

In all cases, the result is a polynomial in the variable $q = \exp(g)$ where g is the coupling constant, whose degree grows with the size of the representation, and with the size of the gauge group.

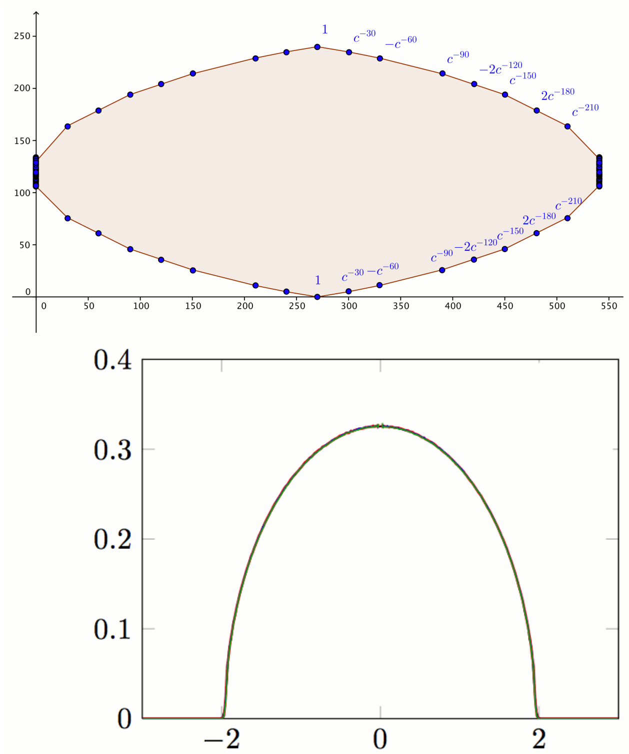
A major challenge is to be able to compute the asymptotics of these polynomials in the limit $g \to 0$, as well as the WKB-like asymptotic expansion: $\log J_{n,R}(q) = \sum_k g^{k-1} S_k(gR)$ (we take a double limit where the size of the representation is of order $1/g$ and/or the size of the gauge group is of order $1/g$).

In 1995, Kachaev made the famous "Volume Conjecture" about the leading term S_0, which has been proved for less than a handful of knots, and remains mostly unproved.

In 2010, Dijkgraaf-Fuji-Manabe extended the conjecture, claiming that all the terms S_k in the asymptotic expansion can be computed by the "topological recursion" (a recursion satisfied by random matrix correlation functions, and by many other enumerative geometry problems). The extended conjecture is so far also unproved, but just checking if it works requires some work. First, the topological recursion needs a starting data, called a spectral curve, and the game is to find the spectral curve for each knot, then compute its S_k by the recursion, and check numerically or prove (or disprove) that they correctly yield the expansion of the knot invariant...

For colored Jones polynomials ($SU(2)$), the spectral curve is conjectured to be the well-known A-polynomial of the knot. In [Borot-Eynard IPhT-T12/037, math-ph: arxiv.1205.2261, EMS Quantum Topology, Volume 6, Issue 1, 2015, pp. 39–138 DOI: 10.4171/QT/60] we verified (and corrected some details in) the conjecture up to order g^3 for a few knots, in particular for the figure-8 knot, and found perfect match !

In [Borot, Eynard, Weisse, IPhT-T14/100, Selecta Math. (2017) 23: 915-1025, math-ph:arxiv.1407.4500], we were able to find the spectral curve corresponding to torus knots embedded in a more complicated space: the sphere S^3 quotiented by a group G, called Seifert sphere. We found the spectral curve for all Seifert spheres of non-negative Euler characteristic, for example the spectral curve for the Poincaré sphere S^3/E_8, is an algebraic curve of degree 240, whose Newton's polygon is:



The spectral curve of the Poincaré sphere S^3/E_8, is solution of a polynomial equation $0 = P(x, y) = \sum_{i,j} P_{i,j} x^i y^j$. We plotted the +points $(i, j) \in \mathbb{Z}^2$ for which $P_{i,j} \neq 0$. The degree is $j_{\max} = 240$ and $i_{\max} = 270$ with 801 points inside the polygon. It is a +curve of genus 1471. Bottom: plot of the solution y of $P(x, y) = 0$ as a function of x. It fits the large size eigenvalues density of a random matrix.

Then in [B. Eynard, T. Kimura, IPhT-T14/088, Lett. in math. phys. , DOI 10.1007/s11005-017-0936-0, math-ph: arxiv.1408.0010], we generalized the approach and found the spectral curve for torus knots with super groups $SU(n|m)$.

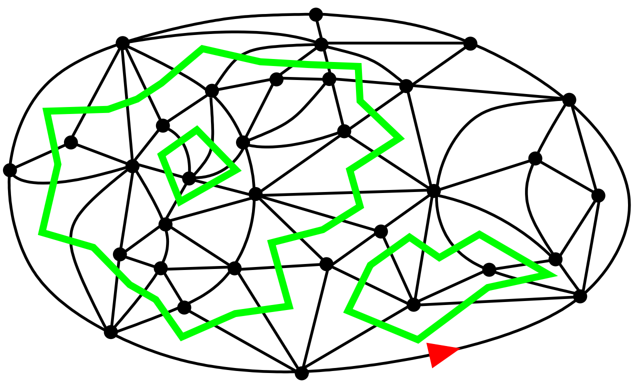
We continue at IPHT to study the intriguing relationship between knots and matrix models, that hides deep mathematics and strong insights about string and gauge theories.

Nesting statistics in loop models

Abstract: We consider the critical $O(n)$ loop model on random triangulations and its continuum counterpart, Liouville quantum gravity decorated by a Conformal Loop Ensemble. In both situations, we study the depth of a typical point, defined as the number of loops winding around it. We characterize the order of magnitude of the depth, its fluctuations and derive an explicit large deviation function. This function is remarkably the same in the two approaches, and involves a functional KPZ relation.

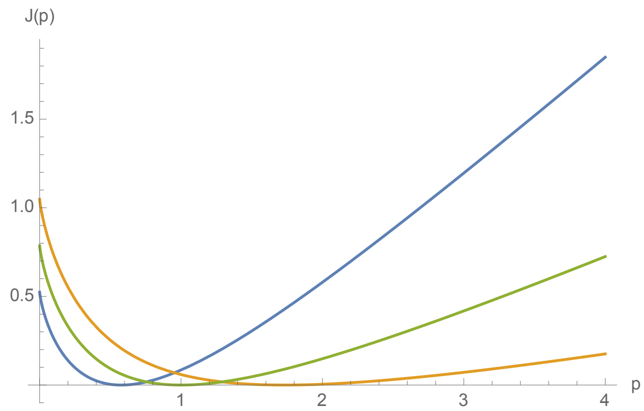
Several interesting models of statistical mechanics can be reformulated in terms of loops: they may describe for instance interfaces between spin clusters in two dimensions, or are obtained by some diagrammatic expansion, etc. The archetype is the $O(n)$ loop model: its configurations consist of all collections of nonintersecting loops on a given lattice, and we attach a nonlocal Boltzmann weight n to each loop in addition to some local weights. For n between -2 and 2, the model is known to have a nontrivial phase diagram, involving the so-called dilute and dense critical points where the loops become macroscopic. This model has been a testbed for many methods: integrability, Coulomb gas, conformal field theory, 2d quantum gravity, etc. In particular, there is a mathematical conjecture stating that a macroscopic probabilistic description of the model at a critical point should be given by the Conformal Loop Ensemble (CLE).

A natural observable for planar loops is the depth of a point, defined as the number of loops that wind around it. The basic question is the following: what is the typical depth of a point? What are the fluctuations and large deviations? In the CLE setting, the question was answered by Miller, Watson and Wilson who computed the multifractal spectrum of extreme nesting. In our project, we address the question for loops coupled with 2d quantum gravity. This can be achieved in two ways: first, at a discrete level, by considering the $O(n)$ loop model on a random triangulation; second, at a continuum level, by considering the interplay between CLE and Liouville quantum gravity (LQG) which was rigorously defined by Duplantier and Sheffield.



A configuration of the $O(n)$ loop model on a triangulation with a boundary.

The $O(n)$ loop model on a random triangulation is well-known to be exactly solvable via matrix integrals. In a series of papers of 2012, Borot, Bouttier and Guitter developed a more combinatorial approach to this model by exploiting the nesting structure. We build on this approach to compute a refined generating function that attaches a different weight to the loops winding around a given reference point (or a boundary) and to the nonwinding loops. By studying its asymptotics, we then show that the typical depth of the reference point scales as the logarithm of the size of the triangulation, the fluctuations are Gaussian, and the large deviations are governed by an explicit rate function $J(p)$.



The large deviation function $J(p)$ for $n = 1, \sqrt{2}, \sqrt{3}$.

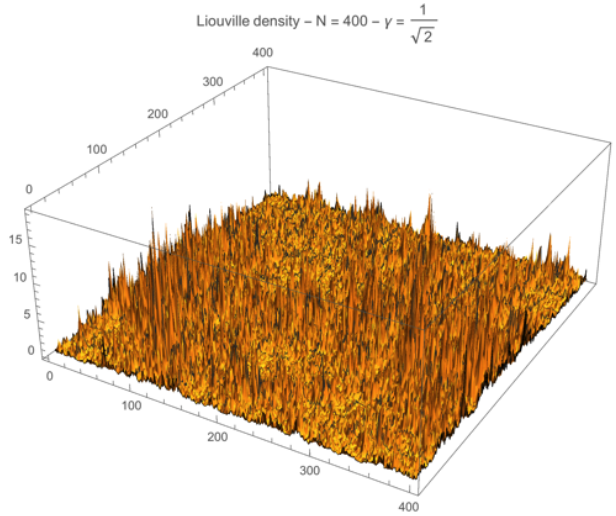
In the continuum CLE setting, the depth of a point is a priori infinite and must be defined through a regularization procedure. The regularized depth is then proportional to the logarithm of the cutoff, and the Hausdorff dimension of the set of points for which the ratio converges to a given constant forms the multifractal spectrum of extreme nesting. In the approach of Miller, Watson and Wilson, the cutoff corresponds to excluding the loops that enter the Euclidean ball of radius ϵ around the reference point. When turning on quantum gravity, the size of a ball should no longer be measured by its radius but by its Liouville quantum measure. This leads to a functional relation involving the celebrated Knizhnik-Polyakov-Zamolodchikov (KPZ) formula relating Euclidean and LQG conformal weights. This seems the first occurrence of such a role for the KPZ formula, which usually concerns scaling dimensions. At the end, we recover precisely the same large deviation function $J(p)$ as for the discrete model.

We obtain, at the refined level of large deviation theory, a rigorous check of the fundamental fact that the universal scaling limits of random planar map models as weighted by partition functions of critical statistical models are given by LQG random surfaces decorated by independent CLEs.

Construction of the Liouville Quantum Gravity Theory

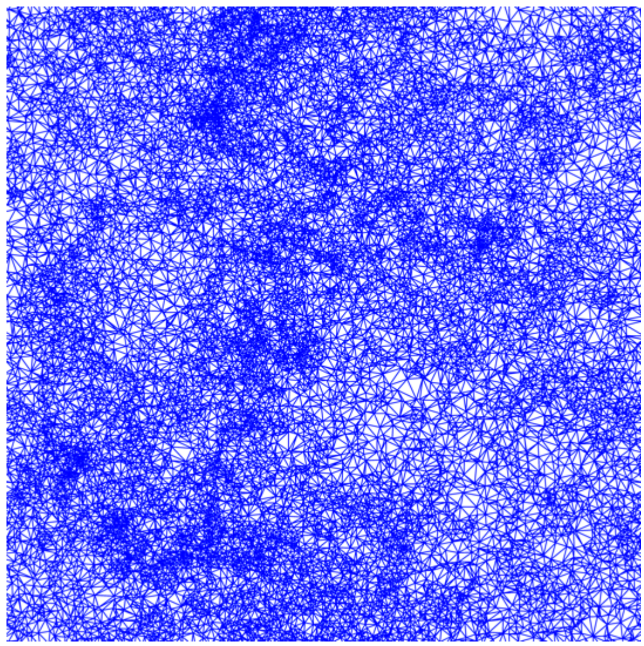
Abstract: The first rigorous full construction of the 2D Liouville Quantum Gravity (LQG) Theory is achieved. This is done on the Riemann Sphere, in its whole perturbative regime $c > 25$, by the theory of probability and of Gaussian multiplicative chaos. The random Liouville field, the vertex operators and the correlation functions are defined. Conformal invariance, Seiberg bounds and KPZ scaling are proven. This is a first step for a better understanding of its relationship with random geometries.

In 1981 A. Polyakov introduced the quantum Liouville theory as a model of non-critical strings. It quantizes the Liouville equation R=-1 where R is the scalar curvature of 1+1 dimensional space-time and is therefore a theory of 2d quantum gravity. Liouville theory is a conformal field theory, it is integrable and it appears in many contexts. Liouville theory and its supersymmetric extensions have been extensively studied in theoretical physics (string theories, quantum gravity, statistical mechanics) and in pure mathematics. But it is also related to the continuum limit of models of discretized space-time, which are studied by various methods (combinatorics, matrix models, integrable systems). IPhT brought major contributions to both the continuum and the discrete approaches. More recently, Liouville theory started to be studied by mathematicians through probability theory, and in relation with stochastic processes such as SLE and CLE. This lead already to many advances in the cases where the non-linearities can be neglected (R=0 equation) which are such that Liouville theory can be replaced by the so-called Gaussian Free Field (GFF).



Louville density field sampling.

In a collaboration with U. of Helsinki and the mathematics departments of ENS and of UPEM, we rigorously constructed the full 2D quantum Liouville theory by probability theory methods relying on Kahane's theory of Gaussian multiplicative chaos. This amounts to a fully rigorous construction of the functional integral over the Liouville field considered by physicists, for the fully interacting and non-linear Liouville theory. This was first done for the theory on the Riemann sphere. By explicit construction of the probability measure and of its moments, the existence and the properties of the general correlations functions of the Liouville theory are established, in particular those which are a by-product of conformal invariance: Seiberg bounds, KPZ scaling laws, Weyl anomaly. This allowed us to propose a precise formulation of the still conjectural relation between LGG and the continuum limit of random planar maps (with and without matter) and with the Brownian map. We generalized this construction to Liouville theory on the torus (establishing modular invariance) and to the case of vertex operators at the Seiberg bound (puncture operators). These works have been the starting point for a growing and successful program (see the recent proof by the Helsinki-ENS-UPEM group of the DOZZ formulas for the 3-point function).



The corresponding planar random geometry configuration, in the random Delaunay triangulation model.

"Liouville Quantum Gravity on the Riemann Sphere", François David, Antti Kupiainen, Rémi Rhodes & Vincent Vargas, Communications in Mathematical Physics (2016) https://doi.org/10.1007/s00220-016-2572-4

String Theory and the multiverse

Abstract: Despite its uniqueness, String Theory has a huge number of solutions with very different observable physics. Each one of them constitutes a possible universe and, besides anthropic arguments, there seems to be no reason why our universe is special in this "multiverse". The IPhT String Theory group has demonstrated that a large number of these vacua are in fact unstable or inconsistent with LHC data. This suggests that String Theory does not support the multiverse paradigm.

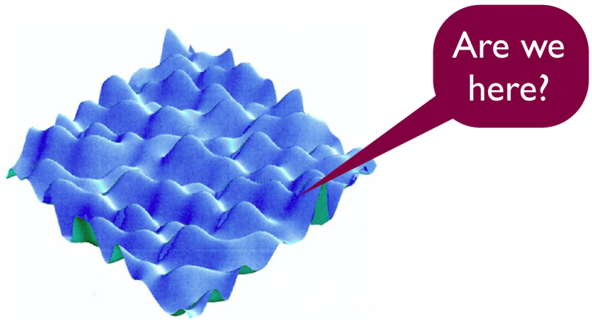
String Theory is the most promising candidate for a theory that unifies all the forces that exist in nature, and could therefore provide a framework from which one may hope to derive all the observed physical laws. However, String Theory lives in ten dimensions, and to obtain real-world physics one needs to compactify it on certain six-dimensional compact spaces that have nontrivial fluxes and have a size much smaller than any scale accessible to observations. Since there exist a large number of such spaces and a huge number of possibilities of putting flux on them, it has been argued that there exist of order 10^{500} four-dimensional String Theory vacua. These vacua have all possible physical laws with all possible constants, and this has led to a radically new view of the physics in which one argues that the constants in the physical laws that we measure in our Universe do not come from an underlying unified theory, but are environmental (anthropic) variables that are determined by where we are in this Multiverse [t17/248]

Over the past few years the IPhT String Theory group has demonstrated that a very large number of these vacua are in fact unstable or inconsistent with the experimental data coming out of the Large Hadron Collider, which in our opinion is a strong indication that the current String Theory constructions do not support the multiverse paradigm.

The main focus of our investigation was the most generic mechanism of constructing de Sitter solutions in String Theory, which consists in uplifting the cosmological constant of the Anti de Sitter vacua one obtains from flux compactifications by placing negatively-charged D-branes (antibranes) inside certain regions of the compactification manifold. We discovered that these antibranes render the solution singular, and we understood that this singularity was not the sign of new physics but rather the sign of an underlying pathology [t13/080].

We have been able to do the only explicit calculations of the physics implied by this singularity, in two opposite regimes of parameters, and have found that in both regimes the singularity of antibranes implies the system has a tachyon [t14/172]. Hence, all the de Sitter universes that have been constructed using multiple antibranes are unstable, rather than metastable as previously believed.

Besides a positive cosmological constant, compactifications of String Theory should also yield models for physics beyond the Standard Model that are compatible with experiments. The standard model of particle physics arises in String Theory from open strings ending on membranes (D-branes) extended along the three-dimensional space. Closed strings propagating along the whole ten-dimensional world of String Theory play the role of the hidden sector, communicating to the matter sector the breaking of supersymmetry that takes place in the extra dimensions in the form of "soft terms" (which have this name because they break supersymmetry without causing ultraviolet divergences).



However, not any soft-supersymmetry-breaking Lagrangian can be obtained this way since the String Theory equations of motion and consistency conditions impose relations between the soft couplings. We have shown that for models realized on D3-branes, the trace of the square of the boson mass matrix is equal to the trace of the square of the fermion mass matrix at tree level, and this equality holds at least up to two loops [t15/183]. A String Theory thus dictates that supersymmetric extensions of the standard model built using these branes cannot have all the scalar superparticles very massive at the same time, and are therefore basically ruled out by LHC.

Hence, our work has shown that a very large number of String Theory constructions, which are at the core of the concept of multiverse, and which people had accepted as correct and consistent for almost 15 years, are in fact inconsistent or incompatible with experiments. Our work has also triggered renewed interest in the physics of uplifting and the multiverse, including several new proposals for uplifting mechanisms, which have opened up new areas of investigation.

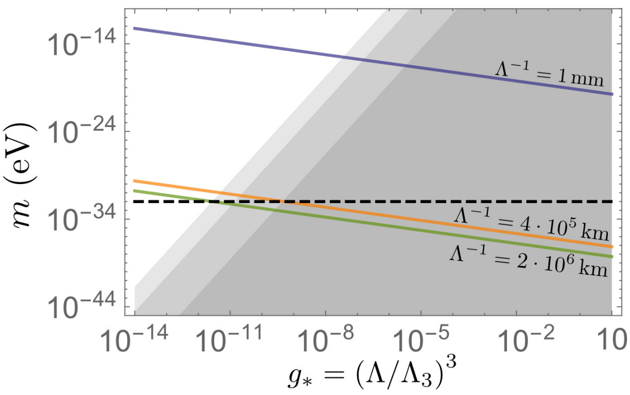
Beyond positivity bounds and the fate of massive gravity

Abstract: Not every effective field theory admits a microscopic completion which is consistent with first principles such as causality, locality, Lorentz invariance and unitarity. Those fundamental requirements are encoded in universal properties of the scattering matrix at low energy, and provide a connection between infrared and ultraviolet physics. This connection has been exploited to derive new and powerful positivity bounds of scattering amplitudes. Those bounds can be used to rule out dRGT-massive gravity in its phenomenological viable form, and to strongly constrain Galileon theories as well as several other interesting effective field theories

The idea that physics at low energy, i.e. large distances, can be described in terms of light degrees of freedom alone is one of the most satisfactory organizing principle in physics, which goes under the name of Effective Field Theory (EFT). The effect of short-distance ultraviolet (UV) dynamics is systematically accounted for in the resulting infrared (IR) EFT by integrating out the heavy degrees of freedom, which generate an EFT built of infinitely many local operators. However, the higher the operator dimension, the smaller the effect at low energy.

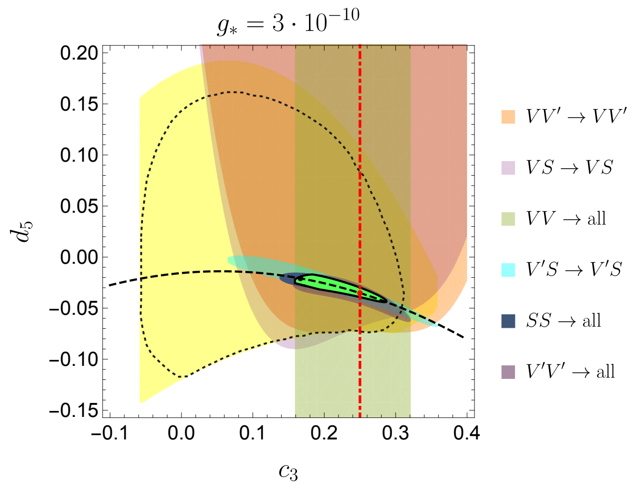
Remarkably enough, extra information about the UV can always be extracted using first principles encoded in the fundamental properties of the S-matrix such as unitarity, analyticity (causality), crossing symmetry, and locality [t15/161,t17/151]. Those imply a UV-IR connection in the form of dispersion relation which gives rise to positivity bounds for scattering amplitudes calculated in the IR. It is possible to derive even more powerful bounds by taking into account the IR contribution in the dispersion relation. Indeed, by construction, the IR part of the dispersive integral is calculable within the EFT.

The resulting beyond-positivity bounds are simple and general. The implementation to interesting theories such as Galileon and (ghost-free) dRGT-massive gravity are just two rewarding examples [t17/151]. For the latter theory, these bounds are summarized in Figure 1 that represents the exclusion region in the mass-coupling plane, see the caption for more details.



Exclusion region for massive gravity in the plane of (g_*, m), where $g_* = (\Lambda_3/\Lambda)^3$ measures the hierarchy between the physical cutoff Λ and the strong coupling scale $\Lambda_3 = (m^2 M_{Pl})^{1/3}$, and m is the graviton mass. The gray region is theoretically excluded by the beyond-positivity bounds. The graviton mass can only be below the experimental bound (dashed horizontal line) at the expense of a premature breakdown of the EFT at macroscopically large distances.

These bounds are so strong that dRGT-massive gravity as known before is ruled out, while the only version that is consistent with our bounds must have an extremely small cutoff, the corresponding length being larger than the moon-earth distance. This is still phenomenologically hard to accept as the motion of the moon matches general relativity's predictions within 1 part in 100 billions. This represents a clear drawback for a theory of gravitation that aims at replacing general relativity. Such a strong conclusion is possible because a massive graviton admits 5 physical polarizations, which allow one to consider several different combinations of scattering amplitudes that enter in the beyond-positivity bounds. Figure 2 shows the bounds, as a function of polarization used, projected in the (c_3, d_5)-plane that defines the most general graviton potential.



Exclusion region in the (c_3, d_5)-plane for dRGT-massive gravity, for fixed accuracy $\delta = 1\%$, mass $m = 10^{-32}$ eV, and $g_* = 3 \times 10^{-10}$, using inelastic channels in the dispersion relations. For couplings larger than $g_* \simeq 4.4 \times 10^{-10}$ the green island disappears, for the same value of the mass, and the model is ruled out.

In the case of Galileon, the beyond-positivity bounds imply that the theory contains symmetry-breaking terms that are at most one-loop suppressed compared to the symmetry-preserving ones.

Alternative gravity after 17 August 2017

Abstract: The recent observation of gravitational waves from a neutron star merger by LIGO/Virgo, immediately followed by the detection of a burst of gamma rays, implies that gravitational waves travel at the speed of light. This observation has dramatic consequences for theories of alternative gravity. In these theories, dark energy acts as a refractive medium for the propagation of gravity and a large class of them is ruled. It also strongly limits the way matter couple to the metrics in theories of massive bigravity.

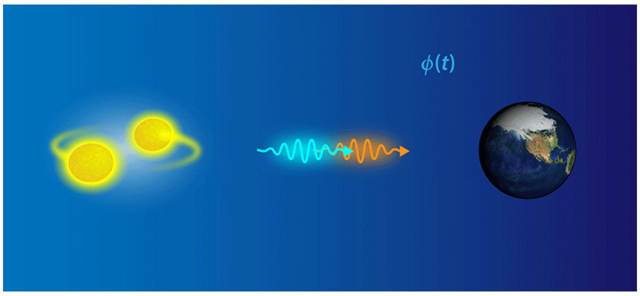
General relativity is a great success. It consistently describes gravity on a wide range of scales and objects, from the sub-millimetre all the way to black holes and galaxies. When applied to cosmological scales, it accounts for the dynamics of the large-scale structure and the expansion of the universe. But the value of the cosmological constant required to explain the current cosmic acceleration is, to most, a puzzle.

That is why an intense theoretical activity has focused on developing alternative theories that dictate that gravity behaves differently on large scales, while recovering general relativity on the better tested Solar System scales. In support, observers have designed cosmic surveys, such as Euclid or LSST, capable of measuring the shapes and positions of galaxies in a very large volume of the universe. Their main goal will be to accurately test general relativity and confirm or rule out its alternatives. But nature has been kind and has allowed us to place some of the tightest constraints to date on many of these alternative theories [t17/206,t18/031] well before any of these telescopes produced a bit of data.

On August 17, 2017, the LIGO/Virgo interferometers detected a gravitational-wave event followed within 2 seconds by the Fermi satellite measurement of a burst of gamma rays from the same location in the sky. These signals has been interpreted as emitted by the same binary neutron merger. The fact that they arrived almost simultaneously, coming from such a great distance, implies that gravitational waves travel at the same speed as light to one part in 10^{15}, beating by many orders of magnitude any of the previous constraints on the relative speeds between gravity and light.

To understand how this event rules out so many alternative theories of gravity, we recall that, in the simplest and most frequently studied case, modifications of gravity entail a light scalar field beside the usual tensor field of general relativity. The most general scalar-tensor theories, known as beyond-Horndeski theories [t14/164], have been developed some four years ago at IPhT and are an extension of theories derived 40 years ago by Gregory Horndeski.

The predictions of these theories vary wildly among models but they all have a common feature: the scalar field exchanges a fifth force that must be screened on short scales, where observational tests are extremely constraining. Fortunately, a screening mechanism is quite natural in these theories as it relies on nonlinear couplings that force the scalar field to mix with the usual gravitational degrees of freedom. This mixing modifies the speed of propagation of gravitational waves. It is as though the scalar field, which must fill the universe and evolve in time to modify the cosmic expansion, constituted a refractive medium for the gravitons as they travel through space, while leaving the uncoupled photons unaffected. The absence of such an effect cuts off a large portion of theories [t17/206] and limits the way screening takes place. Out of the many free parameters of beyond-Horndeski theories, only four are left free to describe the survivors. However, some of these parameters can be constrained by a variety of other cosmological observations showing a beautiful example of how multiple observables are needed to test these models.



The neutron star merger emits gravitational waves (in orange) and gamma rays (in light blue). The two fundamentally different waves, despite travelling 130 million light years, arrive to us almost at the same time. This implies that many modified gravity theories where gravity couples to a time-dependent scalar field, $\varphi(t)$, are excluded. Credit: APS/Alan Stonebraker.

A second alternative way to change the behavior of gravity on large scales, while preserving general relativity on the short ones, is to give the graviton a mass, such as to weaken its strength at large distances. The observation of gravitational waves and their waveforms constrains this mass to be smaller than 10^{-22} eV. But even with such a tiny mass, the only concrete theory of massive gravity that admits a viable cosmological background must involve two dynamical metrics coupled via a potential designed to avoid instabilities. In these bigravity theories, standard matter can consistently couple either to a single metric or to a particular combination of the two. While in the first singly-coupled case the standard graviton propagates with the same speed as light, we have shown that the bounds on the speed of gravitational waves place strong constraints on the doubly-coupled models [t17/073,t18/031], forcing either the two metrics to be proportional at the background level or the models to become effectively singly-coupled.

At IPhT we keep working on the surviving theories and on how future large-scale structure and gravitational wave observations will compete and complement each other in testing gravity.

The Littlest Liquid

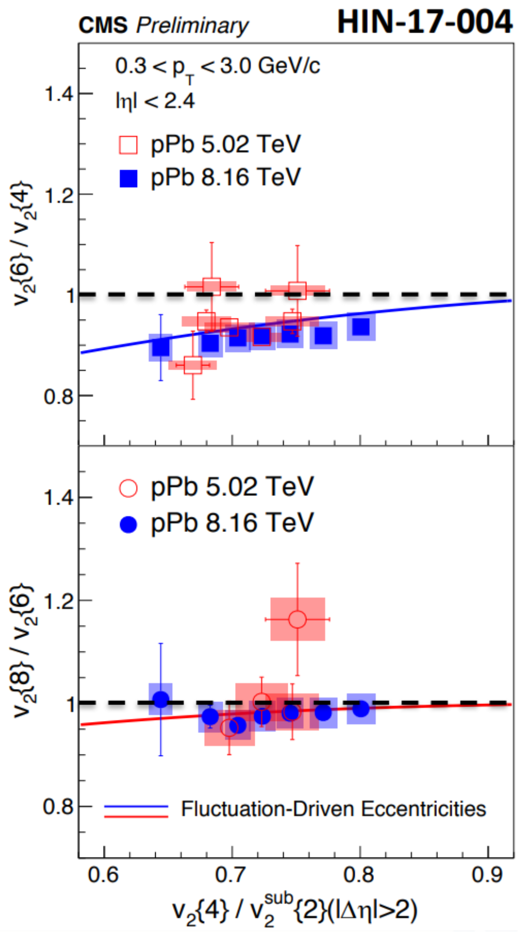
Abstract: Recent results from the Large Hadron Collider suggest that the system formed in a collision between a proton and a lead nucleus behaves collectively as a fluid, the smallest and hottest fluid produced in the laboratory.

The Large Hadron Collider (LHC) can accelerate protons or atomic (Pb82+) nuclei in both directions. It has studied proton-proton collisions, nucleus-nucleus collisions and, finally, proton-nucleus collisions. A nucleus-nucleus (Pb-Pb) collision creates a soup of particles known as quark-gluon plasma (QGP). It has long been known that this state of matter behaves like a continuous liquid. Initially at four trillion degrees Celsius, it rapidly cools by expanding into the vacuum, and eventually transforms into roughly 30000 particles, a fraction of which is detected. In a proton-nucleus collision, however, the proton only impacts a small volume of the nucleus. Physicists did not expect that a fluid would be created from such a small region of impact, and instead assumed that the resulting matter could be described in terms of elementary particle interactions. For this reason, preliminary evidence [arxiv:210.5482] in 2013 that proton-lead collisions had produced a fluid triggered vivid discussions within the high-energy physics community.

The fluid-like behavior is probed by looking at the distribution of outgoing particles in azimuthal angle (the angle that winds around the line of collision), which is slightly anisotropic. This phenomenon is referred to as anisotropic flow. The anisotropy results from the slight inhomogeneities of the density profile right after the collision, which are due to various quantum fluctuations. These inhomogeneties, in a strongly coupled liquid, produce pressure waves (akin to sound waves) that result in anisotropic flow. This effect is analogous to the formation of structure in the early Universe, in which the expanding Universe amplified tiny density fluctuations, resulting in the structures we observe today. For instance, a small elliptic deformation of the initial density profile results in an elliptic deformation of the observed azimuthal distribution, whose magnitude is quantified by a Fourier coefficient v_2.

In a large system, fluctuations are small and their distribution is almost Gaussian. This is the case for the fluctuations of the early universe, where anisotropies are at the level of 10^{-5}, and primordial non-Gaussianities are negligible. In a small system, on the contrary, fluctuations are large: in proton-nucleus collisions, anisotropies are typically at a few percent level. Along with large fluctuations, one typically expects strong non-Gaussianities. These non-Gaussianities are probed by cumulants of higher-order correlations, which vanish for a Gaussian distribution. A sizable 4-particle cumulant was measured by ATLAS in the 2nd Fourier harmonic already in 2013 [arxiv:1303.2084], showing clear evidence of non-Gaussian fluctuations. We pointed out that these non-Gaussianities have universal properties [arxiv:1312.6555]. Technically, these non-Gaussianities are generated by the condition that the Fourier coefficient quantifying the initial deformation is smaller than unity. Therefore, its distribution is bounded, while a Gaussian tail extends to infinity. The cumulants can be calculated exactly to all orders in a simple model, which we used to predict quantitatively the hierarchy of higher-order cumulants. The CMS collaboration tested our prediction by measuring cumulants up to order 8 in collisions at 5 TeV [arxiv:1502.05382] The collisions at 8 TeV recorded in 2016 resulted in much more precise values, which were shown in May 2018 at the Quark Matter conference in Venice (see figure).

This excellent agreement is a strong indication that the observed anisotropies in the momentum distribution result from spatial anisotropies of the density profile, which are carried over to the momentum through pressure gradients. Hence there is growing evidence that proton-nucleus data are explained by the transient formation of a small droplet of fluid.



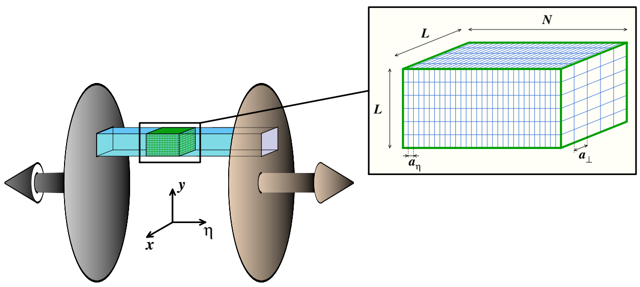
v_2n denotes the cumulant of order n (n particle cumulant) in the 2nd Fourier harmonic. The x axis is the ratio of cumulants of orders 4 and 2. Higher-order ratios are plotted on the y axis. The full line is the analytic, parameter-free prediction of our paper [arxiv:1312.6555]. Full and empty symbols correspond to experimental results from collisions at 8 and 5 TeV, respectively.

Isotropization in heavy ion collisions

Abstract: The isotropization of the local distribution of particle momenta in heavy ion collisions is rather non-trivial because of the competition between scatterings and the longitudinal expansion of the system. We present here the first ab initio attempt to understand this process in terms of the underlying QCD dynamics.

The problem of the thermalization of a system enclosed in a hermetic box is an easy one: just wait (typically, a few mean free paths), and local thermalization is guaranteed to happen. The situation is far less clear cut for an open system expanding freely in space. Indeed, thermalization requires scatterings, while the expansion of the system produces a dilution that reduces the interaction rate. Now, the final outcome depends on a subtle competition between scatterings and expansion.

In heavy ion collisions, realized experimentally at the LHC at CERN in order to study the hot and dense phases of nuclear matter, many observables indicate that the system produced in the collision can be described as an expanding fluid with a very low viscosity. Since the viscosity scales linearly with the mean free path, this suggests that this system has a short mean free path or, equivalently, a high scattering rate throughout a large part of its evolution. From a theoretical standpoint, there are two ways to shorten the mean free path: increase the coupling or increase the density. It turns out that the gluon occupation number inside hadrons or nuclei increases with the collision energy due to soft breamsstrahlung, to reach values of the order of the inverse coupling (this is known as gluon saturation). In the saturation regime, the mean free path is actually as short as it can possibly be, of the order de Broglie wavelength.

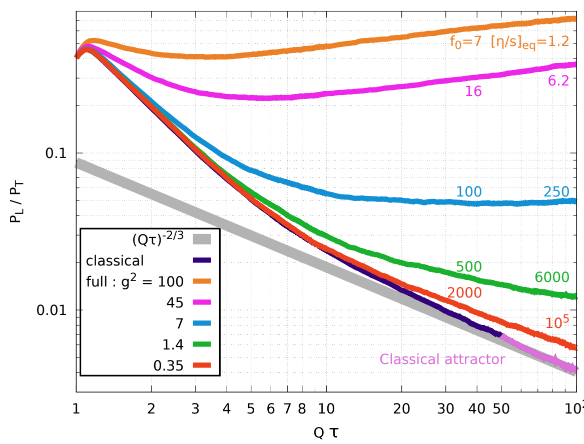


Lattice setup for classical statistical simulations.

The kinematics of high energy collisions is also very asymmetric: the incoming particles have extremely large longitudinal momenta, and only moderate transverse momenta, and the produced system is the siege of a very fast expansion in the longitudinal direction. If the interaction rate is not high enough, this expansion makes the local momentum distribution more and more anisotropic. In [t13/191], we have performed the first semi-classical lattice simulation (see figure above) of the time evolution of the gluon fields in such a collision (the analytical work [t13/190] paved the way for this computation by calculating the appropriate initial condition for these gauge fields, and their fluctuations). This computation showed that the interactions in this system are strong enough to produce a significant degree of local momentum isotropization, despite the longitudinal expansion.

Because of its semi-classical nature, this approach somewhat mistreats the quantum statistics. In particular, we showed subsequently that this approximation has no continuum limit and should be viewed as an effective description. Therefore, alternative treatments where this semi-classical approximation is not used would be highly desirable. One of them is the two-particle irreducible formalism (also known as Kadanoff-Baym equations), that resums the classes of diagrams that are relevant in this problem, while properly handling the quantum statistics. But solving these equations has a very high computational cost because the equations contain a "memory kernel", causing the evolution of the system to depend on all its past history.

A computationally more modest, yet very informative, alternative is to use kinetic theory. In fact, the Boltzmann equation can be obtained from the Kadanoff-Baym equations, by imposing on them a gradient expansion and a quasiparticle expansion. The advantage of the Boltzmann equation is that it is completely local in spacetime, and it allows easily to keep the exact quantum statistics. We have followed this approach in [t15/123], using scalar particles as a toy example. This computation showed that isotropization does indeed occur despite the fast longitudinal expansion, in a time that depends significantly on the value of the coupling. Within this kinetic treatment, we also showed that a strict classical (not semi-classical) approximation completely fails to isotropize the system, and we also obtained a simple kinematic explanation of this failure.



Isotropization in scalar theory in a kinetic description. The curves show the ratio of longitudinal to transverse pressure versus time, for various coupling strengths.

Transposed to the underlying field theory, our result says that classical fields never isotropize, and quantum fluctuations are absolutely necessary for this.

Vacuum-like jet fragmentation in a dense QCD medium

Abstract: We study the fragmentation of a jet propagating in a dense quark-gluon plasma. Using a leading, double-logarithmic, approximation in perturbative QCD, we compute for the first time the effects of the medium on the vacuum-like emissions. We compute the jet fragmentation function and find results in qualitative agreement with measurements at the LHC.

A main goal of the experimental programs at the Large Hadron Collider (CERN) and at the Relativistic Heavy Ion Collider (Brookhaven) is the exploration of the high-temperature, deconfined, phase of QCD matter, the quark-gluon plasma (QGP). Believed to have existed in the first microseconds of the Early Universe, this phase is currently recreated in the intermediate stages of ultrarelativistic heavy ion collisions, albeit for only a very short time (10 fermi, or 10^{-23} seconds). A careful choice of observables is essential in order to extract information about this phase. Such a class of observables refers to the propagation of energetic jets through the plasma.

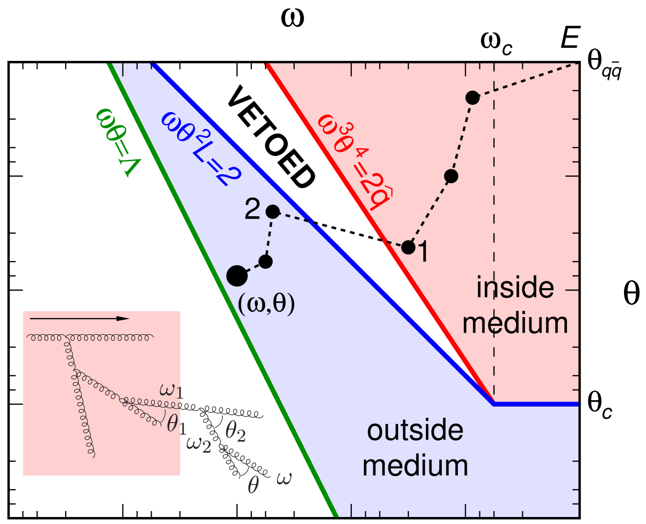
A jet is a collimated spray of particles generated via successive parton branchings (followed by the hadronisation of the branching products), starting with a highly energetic and highly virtual parton (quark or gluon) produced by a hard collision. When the jet is produced in the dense environment of a Pb-Pb collision, its interactions with the surrounding medium lead to modifications in the structure of the jet, known as *jet quenching*. For instance, they can trigger additional parton branchings, leading to energy loss by the jet towards the plasma. By measuring such modifications, one can deduce important information about the medium properties.

To that aim, one needs a proper understanding of the jet evolution via radiation and collisions with the plasma constituents. There are two important mechanisms for gluon radiation: "vacuum-like" bremsstrahlung responsible for the parton shower from large virtualities down to the hadronisation scale, and "medium-induced" emissions triggered by the collisions in the plasma. Taken separately, these two mechanisms are rather well understood, but a unified description of both processes was until recently still lacking. The difficulty stems from the fact that the underlying dynamics is very different in the two cases. For example, vacuum-like emissions (VLEs) evolve according to parton virtualities while medium-induced emissions evolve according to their propagation time.

In [t18/016], we demonstrated that these two mechanisms can be factorized from each other within a controlled, "double-logarithmic", approximation in perturbative QCD. Physically, this is possible since, for a given energy of the emitted gluon, the characteristic emission time is much shorter for a VLE than for a medium-induced emission. Although they follow the usual bremsstrahlung law, the vacuum-like parton showers which develop inside the plasma are modified and their phase-space is reduced compared to the vacuum. Physically, the scattering inside the medium prevents the emission angles to become arbitrarily small. This introduces a *vetoed region* in the energy (ω)–emission angle (θ) phase-space. In the figure, L is the distance travelled by the jet inside the medium and the "jet quenching parameter" $\hat{q}$ is the scattering rate weighted by the squared momentum transfer.

Another important medium effect refers to *angular ordering* [t18/016]. For jets developing fully inside the vacuum, successive emissions occur at smaller and smaller angles, due to destructive interferences between different colour sources. In the medium, the colour coherence of the sources is eventually washed out by rescattering. Since VLEs develop very fast, angular ordering is preserved for all the emissions except for the first emission outside the medium which is produced by incoherent sources and hence can violate angular ordering. This provides additional sources for low-energy emissions at large angles.

Altogether, our pQCD picture for in-medium jet fragmentation predicts a reduction in the number of radiated gluons at intermediate energies (due to the vetoed region in phase-space), and an enhancement at lower energies (due to the lack of angular ordering for the first out-of-medium emission). These predictions are in qualitative agreement with the LHC data, and provide a natural explanation from first principles.



Schematic representation of the phase-space for VLEs, including an example of a cascade with "1" the last emission inside the medium and "2" the first emission outside.

Many Jets at Next-to-Leading Order for the LHC

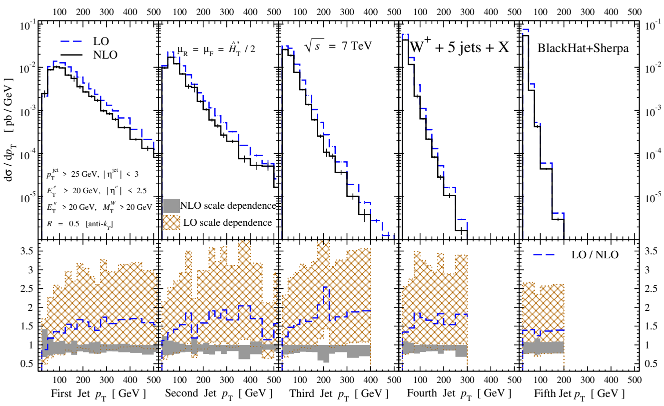
Abstract: The article was the culmination of a series of papers by the BlackHat collaboration devoted to next-to-leading order (NLO) corrections to the production of an electroweak vector boson accompanied by multiple jets at the LHC. Here we computed the NLO corrections to W-boson production accompanied by five jets. It demonstrated that such high-multiplicity processes could be computed successfully and reliably at NLO, and that uncertainties of O(factor of 2 up or down) are reduced to O(10-15%).

The article [t13/114] presented the next-to-leading order QCD predictions for the total cross section and for transverse-momentum distributions in the production of charged electroweak vector bosons (Ws) accompanied by five jets at the Large Hadron Collider, at a center-of-mass energy of 7 TeV. The decay of the Ws into leptons is included, and representative experimental cuts were applied. This was the first NLO computation performed with six final-state objects (vector bosons or jets). The computation used the BlackHat one-loop library along with the SHERPA framework to carry out the calculation. Our collaboration wrote the BlackHat library, which uses modern, so-called "on-shell" methods to compute one-loop scattering amplitudes. SHERPA (written by the eponymous collaboration) provided tree-level matrix elements, Catani-Seymour subtraction terms, and the framework for integrating all contributions over phase space.

An NLO calculation requires several ingredients. These include the tree-level matrix elements for the corresponding leading-order (LO) calculation; the one-loop corrections; and the real-emission corrections. The one-loop corrections arise from the interference of the one-loop and tree-level amplitudes for the basic process. The real-emission corrections arise from tree-level matrix elements with an additional emitted gluon, or a gluon replaced by a quark-antiquark pair. The different ingredients contribute infrared singularities because of the presence of massless particles (gluons and quarks). These singularities ultimately cancel in physical quantities, but require careful management in intermediate stages of a calculation. Dimensional regularization is used to regulate them. A subtraction method is used to extract the singularities that arise in the phase-space integrals over the real-emission contributions, before cancelling them against the singularities explicitly present in the one-loop amplitudes. The latter singularities arise directly from Feynman integrals.

The article builds upon prior work in applying the on-shell approach to concrete predictions for experiments, starting with the first predictions of W+3-jet production for the Tevatron and the LHC several years earlier. With traditional methods, the computation of an amplitude produces a proliferation of Feynman diagrams. This is true even when the final answer is relatively compact, as is the case for the simplest helicity configurations. This proliferation of diagrams reflects the gauge dependence of individual diagrams, and the cancellation of this dependence in the full amplitude. With on-shell methods, these cancellations are squeezed out at an early stage. They rely on underlying properties of amplitudes, such as factorization and unitarity, to express amplitudes in terms of simpler on-shell amplitudes of lower multiplicity. These methods avoid direct use of the off-shell states present inside loops or trees. In the case of one-loop amplitudes, they make use of the decomposition of the result into known Feynman integrals (two-, three-, and four-point integrals). The on-shell methods give expressions for the coefficients of these integrals in terms of on-shell tree amplitudes. These amplitudes are computed numerically in BlackHat.

Vector-boson studies at high multiplicity can be used to probe corners of phase space where contributions from new physics can arise. These include production of heavy particles which ultimately decay into multiple jets and invisible particles giving rise to missing transverse energy. This is a classic signature of supersymmetric theories, and may be characteristic of dark-matter production more generally. With increasing multiplicity, the theoretical uncertainties at LO grow quickly, and LO predictions are not quantitatively reliable. NLO predictions reduce this uncertainty dramatically, and provide a reliable result. This article demonstrated the feasibility, using modern methods, of such a calculation which would have been far beyond what is practical with traditional Feynman-diagram approaches.



The transverse-momentum distributions of the leading five jets in W+ + 5-jet production at sqrt s = 7 TeV at the LHC.

The growth of amorphous order at the glass transition

Abstract: By combining recent theoretical with experimental breakthroughs we show that the glass transition is accompanied by the growth of "amorphous order", which means that the arrangement of particles, although apparently random, is ordered on a scale that grows approaching the glass transition.

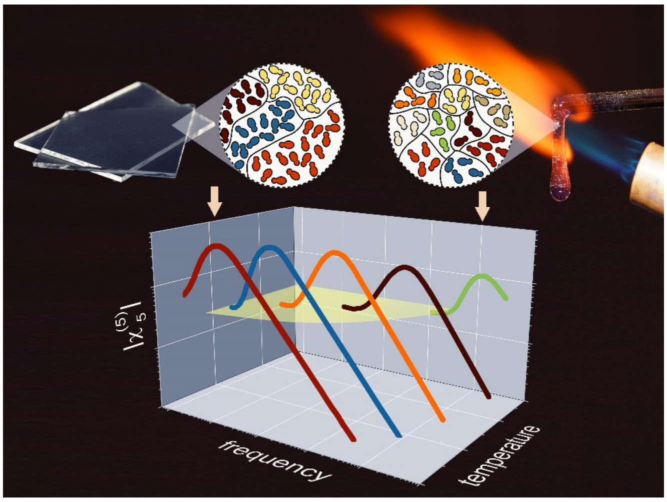
Are glasses just liquids that stop to flow or are they fundamentally different? Recent theoretical results suggest that the formation of amorphous solids is driven by the growth of amorphous order, which is the counterpart of long-range order for glasses.

Two major difficulties hampered experimental investigations of this crucial issue: (I) no accessible experimental probes of amorphous order were known; (II) amorphous order is expected to develop on scales which are quite modest.

Our central theoretical idea to circumvent these difficulties is based on a generalisation to glassy physics of a general property of critical phenomena: when long-range order develops, approaching the critical temperature, the response (or susceptibility) to the application of an external field E (for example an electric field) diverges, and does this more strongly the higher is the non-linear response. Moreover, the comparison of the growth of different non-linear responses allows one to obtain the fractal dimension of correlated regions. These results represent the culmination of an intense theoretical effort started by G. Biroli and J-P. Bouchaud in 2005.

By measuring dielectric non-liner susceptibilities in supercooled liquids we show that indeed the third-order and the fifth-order dynamical non-linear responses, χ_3 and χ_5, grow approaching the glass transition, the latter more strongly than the former (see Figure), hence providing a strong evidence of the criticality of the glass transition. By comparing χ_3 and χ_5 we find that the correlated regions responsible for the glassy slowing-down are compact, i.e. their fractal dimension is equal to the spatial dimension, thus showing that the glass transition has unusual properties compared to usual second-order phase transitions, e.g. a diverging time-scale but non-fractal correlations. These findings, which come from an experimental tour de force, confirm predictions of thermodynamic theories of the glass transition.

Our results, that combine theoretical results with experimental advances, shed new light on the nature of glasses and the glass transition.



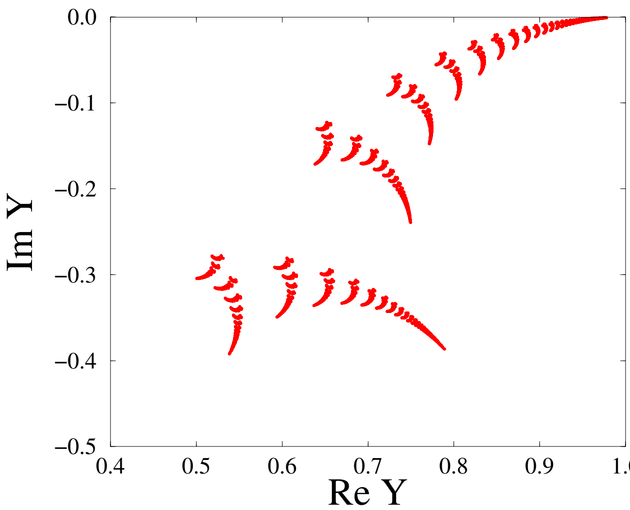
The non-linear response of a super-cooled liquid to an electric field was measured as a function of temperature and frequency. When the material changes from the liquid state (upper right) to the glass state (top left), there is a growth of "amorphous order" on larger and larger sizes. This evolution is a strong evidence of the existence of an underlying phase transition associated to the formation of amorphous solids. For a simple high temperature liquid, like usual water, the curves would have no maximum. (Illustration credit: Experimental Physics V, University of Augsburg)

Fifth-order susceptibility unveils growth of thermodynamic amorphous order in glass-formers, S. Albert, Th. Bauer, M. Michl, G. Biroli, J.-P. Bouchaud, A. Loidl, P. Lunkenheimer, R. Tourbot, C. Wiertel-Gasquet and F. Ladieu, Science 10 Juin 2016, DOI: 10.1126/science.aaf3182.

Classical and quantum survival to static traps

Abstract: The dynamics of classical and quantum particles in the presence of static traps have been analyzed within the framework of continuous-time lattice random walk. As a general rule, trapping sites are far less efficient to absorb quantum particles than classical ones. In the presence a concentration of identical but randomly placed traps, the classical and the quantum survival probabilities obey a stretched exponential temporal decay, albeit with different exponents. For the one-dimensional quantum problem, a full prediction for the amplitude of the decay law has been derived, including its dependence on the trap density and strength.

Discrete-time quantum walks have become a popular tool to implement advanced algorithms in quantum information theory. From a physical point of view, continuous-time quantum walks provide the relevant setting to investigate the dynamics of various systems in the quantum coherent regime, such as ultra-cold atomic gases. A quantum walker launched from a given site propagates ballistically and its wavefunction exhibits sharp ballistic fronts. This is to be contrasted with the diffusive scaling and the rather dull Gaussian probability profile of a classical walker. As a general rule, the dynamics of quantum walkers are qualitatively different from those of their classical counterparts, i.e., Brownian particles. A panoply of such differences have been investigated by analytical means in the case of continuous-time walkers on the one-dimensional chain. In the presence of a single static trap on the infinite chain, a classical walker is absorbed with certainty after a finite lapse of time. In the quantum world, a static trap is modelled by a local optical potential. A quantum walker efficiently takes advantage of interference effects to avoid such a trap, so that it survives forever with a nonzero – and in fact rather large – probability, even when its initial position is very close to the trap. In the presence of a finite concentration of identical but randomly placed traps, the survival probabilities of a classical and of a quantum walker obey a stretched exponential asymptotic decay in time, albeit with different stretching exponents. In the one-dimensional situation, we have obtained in [t13/265] the first full analytical prediction for the asymptotic decay law of the quantum survival probability, including the dependence of the amplitude on the trap density and strength. The latter result involves a construction based on a sequence of extremal points on a fractal in the complex plane, such as that shown in the figure. Yet other features of the dynamics of quantum walkers have been investigated. As soon as many-body dynamics are concerned, quantum statistics plays a role, and one has to specify whether the walkers are bosons or fermions. Bound states of quantum walkers exhibit many ballistic internal fronts, besides the two extremal ones, corresponding to internal singularities in the empirical velocity distribution. The return probability of a system of quantum walkers launched from a compact non-equilibrium initial configuration has been shown to exhibit a power-law temporal decay, with an exponent that depends quadratically on the number of particles. For tight-binding fermions in one dimension, by expressing this echo probability as a Selberg-Mehta integral, it has been possible to derive closed-form expressions for the amplitudes of the latter power-law decay, and to study the scaling regime where time and the number of fermions are both large and comparable to each other.



The problem of a quantum walker propagating on an infinite chain endowed with a finite concentration of identical but randomly placed traps. Fractal support of the invariant distribution of the associated complex Riccati variable.

An exact formula for single-file diffusion

Abstract: A tagged particle in a narrow channel with excluded volume interactions displays *anomalous single-file diffusion* in which mean-square fluctuations of the position grow as the square-root of time – instead of scaling linearly with time. Using techniques inspired from the theory of integrable systems, we have derived a closed formula for the distribution of a tracer in the Symmetric Exclusion Process, a pristine model of single-file diffusion. Our results are valid at all times and for initial conditions far from equilibrium.

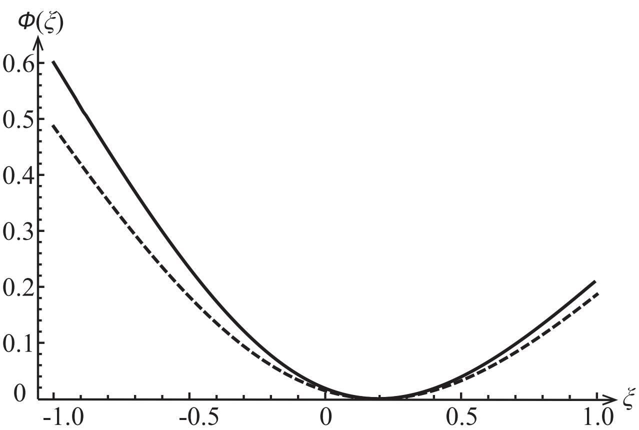
The collective dynamics of a complex system can be probed by attaching a neutral tag to a particle, that does not alter its interactions with the environment, and by monitoring the position of the tagged particle (or tracer) in time. This technique is a powerful tool to study flows in hydrodynamics, material sciences, biological systems and even social groups (pedestrian flow). The typical example is the Brownian motion of a grain of pollen immersed in water at thermal equilibrium, which diffuses as the square-root of time.

Diffusive behaviour is very robust. But it can be altered in presence of long-range correlations or if the environment is out of equilibrium, resulting in unusual collective behaviour. Correlations are usually enhanced in low dimensional systems such as narrow quasi-one-dimensional channels, in which the order amongst the particles is preserved because of steric hindrance. For such a single-file motion, the typical displacement of a tracer at large times grows as $t^{1/4}$, much slower than the usual $\sqrt{t}$ law, regardless of the precise form of the interaction. This anomalous *single-file diffusion* has been demonstrated in various experiments involving different types of physical systems such as capillary pores, carbon nanotubes or colloids.

In a one dimensional lattice, a pristine model for single-file diffusion is provided by the Symmetric Exclusion Process (SEP), where particles perform symmetric random walks and interact by hard-core exclusion. This stochastic lattice gas model, which plays a key role in non-equilibrium statistical mechanics, was introduced by F. Spitzer in 1970 as a N-body extension of the simple random walk. This system is is amenable to quantitative analysis with the help of a large variety of techniques. In particular, being equivalent to the quantum Heisenberg spin chain, the SEP can be solved by the Bethe Ansatz.

The statistics of the position of a tagged particle – or tracer – immersed in a bath of particles performing a SEP has been the subject of numerous works. For a uniform initial density, the variance of the position of a tagged particle has been calculated exactly by Arratia in 1983. The key result is that the variance, after a transient linear growth with time, scales as $t^{1/2}$ in the long time regime – with a crossover time scaling as the inverse of the density square. These calculations have been rederived in many subsequent papers, at various levels of physical intuition or mathematical rigor. Besides, it has been understood that the trajectory of a tracer behaves as a fractional Brownian motion with Hurst parameter 1/4. However, the exact distribution of a tagged particle, its higher cumulants (prone to experimental measurements) and the large deviations from the typical behaviour have remained an open problem for the last 35 years.

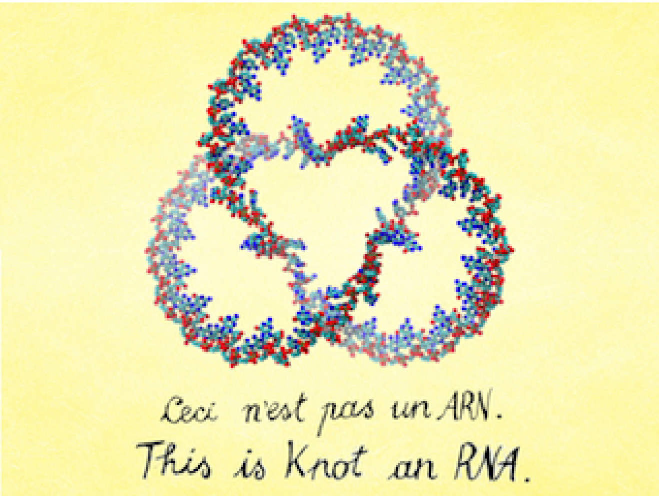
In a recent work [t17/029], we have found the exact formula for the distribution of a tagged particle in SEP, valid at any time. Our approach uses the powerful mathematical arsenal of integrable probabilities developed recently to solve the one-dimensional Kardar-Parisi-Zhang equation. The asymptotic limit of our formula provides us with the cumulants of the position of the tracer at all orders and allows us to calculate the large deviation function. Thus, we have fully elucidated a problem that has eluded solution for decades. Our results are not restricted to the equilibrium case and the system can be prepared out of equilibrium by imposing a step initial density profile, with two different average densities on the right and on the left of the origin. We also prove a Gallavotti-Cohen Fluctuation Relation that implies that the Einstein relation remains valid, even in the context of single file diffusion. Finally, our exact result provides a highly nontrivial check of the Macroscopic Fluctuation Theory of G. Jona-Lasinio et al., the most promising current framework for analyzing systems far from equilibrium.



Large deviation functions of the tracer position in the SEP (solid curve) and in the case of reflective Brownian particles.

Absence of knots in known RNA structures

Abstract: Ongoing effort has so far established that knots are present in many globular proteins and abound in viral DNA packaged inside bacteriophages. RNA molecules, however, have not yet been systematically screened for the occurrence of physical knots. We have undertaken the systematic profiling of the several thousand RNA structures present in the Protein Data Bank (PDB). The search identified no more than three deeply knotted RNA molecules. Their genuine knotted state is, however, doubtful based on the detailed structural comparison with homologs of higher resolution, which are all unknotted.



No one had checked before, but RNA, the nucleic acid involved in many cell functions including protein synthesis, appears to be the only « strand of life » not to have knots.

Over the years, advances in structural biology have firmly established that both proteins and DNA, although subject to evolutionary selection, do not escape the statistical law whereby a sufficiently long and compacted molecular strand will inevitably be entangled. However, no one to date had looked into the case of RNA.

Using the structural description provided for approximately 6,000 RNA chains entered in the Protein Data Bank, a team of researchers from the SISSA (Italy) and the IPhT has performed a thorough study of the presence of knots in these biopolymers.

In order to detect knots, they used the following methods: i) Circularize the RNA chain by joining its extremities using the « minimally invasive » scheme. ii) Simplify locally the structure by iteratively removing obviously unknotted parts. iii) Compute the Alexander polynomial, and for more complex knots, the Doker code (which unambiguously identifies knots up to 16 crossings). The outcome is that over the 5466 studied structures, only 3 came out with a knot.

Looking more closely at these structures, they noted that all 3 structures had been obtained by the cryo-em (electronic cryomicroscopy) method, and in all 3 cases, the experimentalists had stressed the presence of strong uncertainties in the resolution of the structure, particularly in the knotted region! In addition, RNAs with very homologous sequences and structures, but resolved with more accurate techniques (such as crystallography), do not exhibit such knots. The authors thus concluded that these knots are probably experimental artifacts and that RNA is the only strand of life which does not have knots.

The reasons for this apparent simplicity is probably manifold: evolution may have selected unknotted sequences, since they fold more rapidly and more reliably; they could be treated more efficiently by the cellular machinery, ... And maybe, after all, we will find knots in the RNAs that will be discovered in the future!

An Exact Realization of an SU(2) symmetry around an anti-ferromagnetic Quantum Critical Point

Abstract: For nearly thirty years, the search for a room-temperature superconductor has focused on exotic materials known as cuprates, obtained by doping a parent Mott insulator. Recently a body of experimental probes suggested the presence of a fourth forgotten player, charge ordering-, as a direct competitor for superconductivity. In this project we propose that the relationship between charge ordering and superconductivity is more intimate than previously thought and is protected by an emerging SU(2) symmetry relating the two. The beauty of our theory resides in that it can be encapsulated in one simple and universal "gap equation", which in contrast to strong coupling approaches used up to now, can easily be connected to experiments.

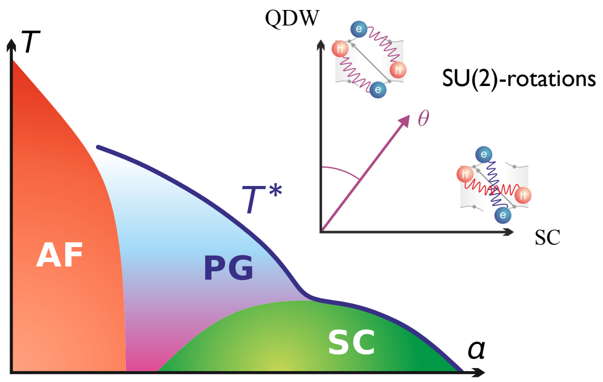
In the most famous family of unconventional superconductors, the cuprate family, superconductivity emerges out of a doped Mott insulator. Two mysterious phases in the normal state of the compound have been identified, the strange metal phase characterized by a linear in T resistivity and the pseudo-gap phase where density of electrons is depleted without any obvious symmetry breaking [Norman03]. Recent experiments indicated the presence of charge ordering in the pseudo-gap region. For the first time since the discovery of superconductivity in cuprates, a fourth player-"charge order"- in the physics of these compounds has to be considered seriously. Experimental evidence was first found in Scanning Tunneling Microscope through imaging reconstruction in 2002 with an ordering wave vector Q* parallel to the crystalline directions of the lattice [Hoffman02], and then, in 2007, quantum oscillations showed a re-construction of the Fermi surface under a magnetic field of 17 T.

One line of thoughts to understand the phase diagram of cuprates, points out the similarities with that of many other unconventional superconductors, where SC appears near a magnetic quantum critical point (QCP), which is a phase transition at zero temperature-, such as heavy fermions, quasi-2D organic SC and iron based superconductors. The anti-ferromagnetic QCP provides a well-defined singularity, which enables theoreticians to derive universal features of this compound.

In the process of studying the anti-ferromagnetic QCP in two dimensions, we discovered to our surprise, that the QCP is not stable and instead leads to the formation of a precursor composite order combining charge ordering and Cooper pairing within an SU(2) symmetry [t13/129]. Maybe the simplest way to understand the concept of SU(2) symmetry is by analogy with quantum chemistry. When two energy levels are degenerate, it can be an accidental feature, or it can be related to an underlying symmetry protecting the degeneracy. The idea is similar here, with the equivalent of the two energy levels being the d-wave Cooper pairing state and the d-wave charge channel. If they are degenerate, one can say that an SU(2) symmetry is protecting them. If they are very close in energy, the SU(2) symmetry is mildly broken but the level splitting can be traced in the experiments (see Fig.1).

In our paper the emergence of the SU(2) symmetry requires a very simplified model where the Fermi surface is reduced to eight hot spots and the electron dispersion is "linearized" at these hot spots. In these conditions the two components of the composite order parameter are fully degenerate and the SU(2) symmetry is exact. In order to show this, we solved the gap equations, for both orders d-wave SC and d-wave bond charge order, and showed they are fully degenerate within this model.

These findings arrived in synchronicity with the burst of experimental data showing evidence for charge ordering, and thus put the charge order and the related SU(2) fluctuations as a key concept for generating the pseudo-gap. They revived the interest for top down theories, since contrarily to strong coupling approaches, the gap equation describing the SU(2) order is malleable enough to connect with experiments. In following works, we have been making the connection to experiments in order to put our theory on solid grounds (see e.g. [t15/241,t15/242,t17/216]).



Generic phase diagram of cuprate superconductors with respect to oxygen doping. In the insert, we illustrate the fluctuations between SC and bond state charge order. At T=0, the SU(2) symmetry is broken to the SC state, but thermal fluctuations restaure it up to T.*

[Hoffman02] J.E. Hoffman et al., Science 295, 466 (2002).
[Norman03] M. R. Norman & C. Pépin, Rep. Prog. Phys. 66, 1547 (2003).

Clustering by no backtracking: New spectral algorithm for data analysis

Spectral methods are among the conceptually simplest algorithms for unsupervised data analysis and dimensionality reduction, and are of choice in many applications. However, in many of these applications relations between unknown variables lead to a sparse observed structure. Many tasks of interest can be formulated as recovery of the values of the hidden variables from these observations. For sparse observations all standard spectral methods are troubled by presence of spurious large eigenvalues unrelated to the unknown variables.

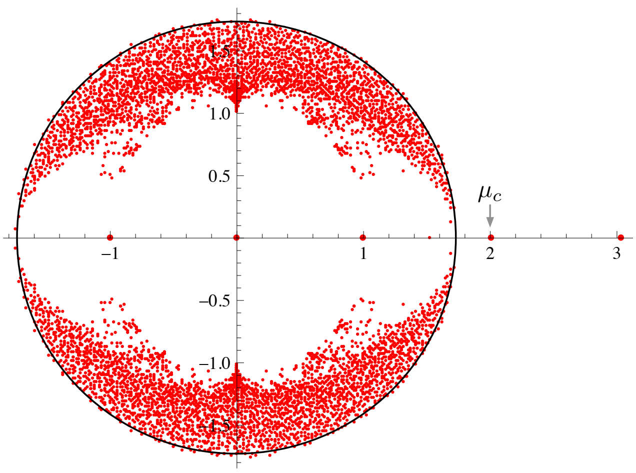
We were motivated by results obtained in our previous work [t11/253,t11/074] that established phase transitions delimiting the region of parameters for which recovery of hidden variables is possible with efficient algorithms in the problems of clustering of networks. Our theory was based on a detailed analysis of the stochastic block model for clustering of in networks. We unveiled relations between first order phase transitions, associated region of metastability and typical computational hardness.

By exploring how spectral algorithms could possibly match the above algorithmic thresholds, we discovered a transformation of the data-matrix that destroys the spurious eigenvalues and allows optimal performance even for sparse datasets [t13/152]. This transformation leads to the so-called non-backtracking matrix, that has remarkable spectral properties maintaining a strong separation between the bulk eigenvalues and the eigenvalues relevant to cluster structure even in the sparse case. The spectrum of this operator is depicted in the enclosed figure. When there is not structure in the dataset then the spectral gap is as large as it can possibly be, thus generalizing the notion of Ramanujan to non-regular graphs and matrices. In [t13/152] we further showed that the corresponding clustering algorithm is optimal for graphs generated by the stochastic block model, detecting communities all the way down to the theoretical limit. We also showed the spectrum of the non-backtracking operator for some real-world networks, illustrating its advantages over traditional spectral clustering.

Interestingly we derived this non-backtracking operator by linearizing the belief propagation equations around the paramagnetic fixed point. Similar calculation has been done in dozens of papers in order to analyze the de Almeida-Thouless line in spin glass-like systems. The main innovative idea of our work is simple but powerful - to use this calculation as an algorithm. It turned out to be a rather influential idea, and that the range of applications for algorithms based on the non-backtracking operator is wide.

In [t14/297] we proposed to replace the non-backtracking operator by a simpler object, a symmetric real matrix known as the Bethe Hessian operator, or deformed Laplacian. We showed that this approach combines the performances of the non-backtracking operator, thus detecting clusters all the way down to the theoretical limit in the stochastic block model, with the computational, theoretical and computer-memory advantages of real symmetric matrices.

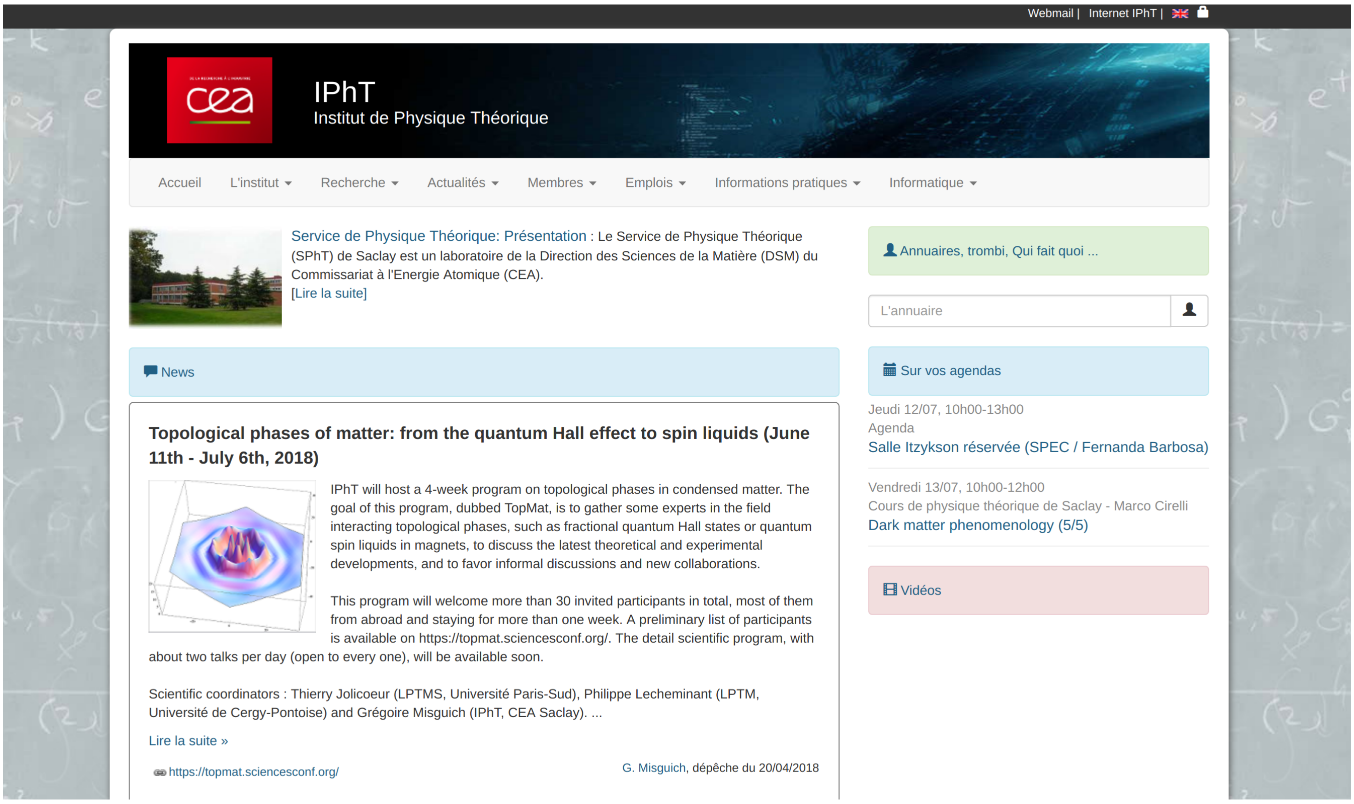
In [t14/298] we studied percolation on networks, which is used as a model of the resilience of networked systems such as the Internet to attack or failure and as a simple model of the spread of disease over human contact networks. We reformulated percolation as a message passing process and demonstrate how the resulting equations can be used to calculate, among other things, the size of the percolating cluster and the average cluster size. The calculations are exact for sparse networks when the number of short loops in the network is small, but even on networks with many short loops we find them to be highly accurate when compared with direct numerical simulations. By considering the fixed points of the message passing process, we also showed that the percolation threshold on a network with few loops is given by the inverse of the leading eigenvalue of the non-backtracking matrix. This study was innovative mainly in the sense that it leverages existing analytical approaches to percolation to an algorithms that is usable on a given graph – this is an important direction in today's research where many problems come together with data that can be explored algorithmically.



The spectrum of the non-backtracking matrix for a network generated by the stochastic block model with 4000 nodes, average degree 3, nodes 5 times more likely to be connected to another node in the same group than in another group. The leading eigenvalue is at 3, the second eigenvalue is close to 2, and the bulk of the spectrum is confined to the disk of radius square root of 3. The spectral algorithm that labels vertices according to the sign of second eigenvector (summed over the incoming edges at each vertex) labels the majority of vertices correctly.

Computer network reorganization and new institute websites

Abstract: Our computer infrastructure has recently been moved from the CEA-EXTRA network to the CNRS network. In parallel, the website of our institute has been completely overhauled in order to modernize the platform on which it is running, and to reorganize its content. A website dedicated to hosting information about our program of courses has also been created.



Until the end of 2017, the computer network of IPhT was attached to the CEA-EXTRA network. Although this offered a slightly more open network than the CEA-INTRA (where most of CEA computer infrastructure resides), it was not as open as one may expect of the computer network of an academic institution, which caused difficulties for our visitors or for using certain common services such as videoconferencing. With the development of the Université Paris-Saclay, it became technically possible to migrate out of the CEA-EXTRA, by attaching our network to that of CNRS. The first phase of this migration, realized before the summer 2017, was to move our email boxes to a mailserver hosted and administered by RENATER. The second phase consisted in moving all our computer equipment from the CEA-EXTRA to the CNRS network. This was realized in the end of 2017, in a way that was essentially transparent for the users.

At the same time, it became increasingly obvious that our website was becoming more and more obsolete, both in technical terms and in the organization of the content that had piled up over the years. A workgroup of users was set up in order to produce the tree structure of the new website, that was then handed to our computer administrators in order to cast it into an up-to-date version of the PhoCEA engine.

A separate website was also created from scratch in order to host information about our program of academic courses, and to archive all the data about past courses. In the meantime, we also made the acquisition of video recording equipment, that we are now using to record lectures and seminars. These recordings are available on the youtube channel IPhT-TV.

4- Organisation and life of the research unit (or the team/theme if relevant)

Quantitative data

Please, fill out the table "Synth personnels unité ANG " in the Excel file "Données du contrat en cours".

Management, organisation and scientific animation

Please describe here the structures and tools of the unit, or team/theme if relevant, (managing team, lab council, lab scientific council, etc.) for managing funds, human resources and scientific animation.

Even if the director of IPhT has the full responsibility for the decisions, the functioning of the Institute is steeped in collegiality. This tradition has proved its usefulness over the years and is reflected in a number of light structures which have a life of their own, but on which the director heavily relies for advice.

DIRECTION

The director of the Institute is nominated by CEA and by CNRS. He is assisted by two deputy directors, one scientific director and one administrative director. They work in close collaboration and some tasks are delegated to the vice directors.

SCIENTIFIC COUNCIL

The scientific council (conseil scientifique) is an internal structure with an advisory but important role. It deals with scientific issues, and meets regularly. The director and his deputies are ex-officio members. The other members are renewed every two years via elections, and can only hold two successive seats. Only permanent researchers are eligible. During the first meeting after the elections, the new scientific council may co-opt one or more members. It also chooses a secretary responsible for preparing and scheduling meetings, and for writing reports. The scientific council takes advice from members of the lab on specific occasions.

The main discussions concern recruitments, fund allocations, financial participation to the organization of conferences, and in general anything that is relevant for the scientific policy and scientific management of the Institute. Permanent researchers are informed in advance of the agenda of the next meeting, and can suggest further items.

LABORATORY COUNCIL

The laboratory council (conseil de laboratoire) is dedicated to daily life and practical and organizational issues. The principles for its designation and working are analogous to those governing the scientific council, with the important but natural difference that in addition to permanent researchers (the members of the scientific council), the support team, graduate students and postdocs are represented, each by one or two elected members.

The laboratory council plays the role of "conseil d'unité" in CEA.

The role of the Institute council is important, if only because of the spectacular rise in the number of non-permanent members. Their adequate integration in the Institute is crucial.

SCIENTIFIC GROUPS

The researchers are affiliated to three thematics "groups", which are labelled by tradition "A", "B" and "C". They roughly span the above-mentioned themes, A – Mathematical Physics, B- High Energy and Cosmology, C- Statistical and Condensed Matter Physics.
These "groups" are rather lightweight structures, and of approximately equal size. Their main purpose in the recent years is:

- (i) to manage the (relatively meagre) CEA budget for invitations and travel,
- (ii) to provide a framework for discussions about scientific prospective and policy issues
- (iii) feed up the discussions and management done by the Scientific Council and the Direction of IPhT.

Each group has a "responsable" who acts as a coordinator and animator. Each group has typically one or two meetings per year. Despites several attempts to think about something different, this organization seems to make people happy. Note that some researchers of group B and C have some or all of their results presented in the first theme of this report. At least one researcher is affiliated both to groups A and C. And the boundaries A/B and A/C are especially permeable, with some long-lasting and occasional inter groups collaborations.

MISCELANEOUS

On rarer and special occasions, a general assembly of the Institute is called by its director.

A "réunion de rentrée" is organized at the beginning of each academic year, typically the first week of October. It is the opportunity to introduce to everybody the new students and postdocs, to exchange news and to have an informal Q&A session on the situation of the Institute.

A "Colloque de l'IPhT" i.e. a three-day internal workshop in some external "retreat" location used to be organized every two years. The last one took place in 2012. Due to the shortage of funding, no such Colloque was organized in the present period 2012-2017. A Colloque is nevertheless scheduled in October 2018. The Colloque consists in scientific presentations by researcher of the Institute and some invited guests, some non-scientific presentations from the staff, as well as general discussions sessions on various matters: scientific prospective, life of the Institute, etc.

COMPUTER RESSOURCES COMMISSION

A "Commission Informatique" gathers two members of the direction (usually the two vice directors), members of the computer and IT team, some users (on a voluntary and cooptation basis) to discuss the important issues of the computer and computing ressources of the institute (local network, web servers and web service, allocation of the IPhT proper funds allocated to these resources, etc.). This "Commission informatique" exists since a long time, and has played a very important role in the prospective and management of our computing and IT resources. During the period the discussed and advised the Direction on the very important decision to quit the CEA "Bulle Recherche" network and to move to the Paris-Saclay external network (see the relevant Highlight).

LIBRARY

IPhT has a library, shared with SPEC. This is a useful resource. For a long time it was used for journals and books. Nowadays we maintain a policy of buying books and keeping up to date our collection (not to mention replacing the "disappearing" items). We are thinking of moving off some of our old scientific journal collections in order to reorganize the space to provide more quiet, free, open workspace for reflexion and reading.

The library, as well as our documentation resources, are managed by our librarian.

SCIENTIFIC ANIMATION

IPhT runs weekly seminars:

- Mathematical Physics Seminar
- Statistical Physics Seminar
- Matrices, Strings & Random Geometries Seminar
- High energy and cosmology seminar

IPhT runs also a Colloquium style seminar ("Séminaire général de l'IPhT). These last three years it is run on a monthly basis.

IPhT runs also a new internal outreach seminar ("séminaire de vulgarization") on a monthly basis.

Members of IPhT participates also to the management of some seminar series outside IPhT. Let us mention

- Théorie de la Matière Condensée sur le Plateau (usualy taking place in LPS Orsay)
- Les « Rencontres théoriciennes » (taking place at IHP)

The annual Itzykson meetings (rencontres Itzykson) are also an important element of our scientific animation.

LECTURES PROGRAM

Since 1997, IPhT runs a series of lectures at the graduate (and sometimes more advanced) level. This was new at that time, and is now a well-established series. It aims at students and researchers in the Great Paris area, not only of IPhT, of course. Since it is also aimed at the researchers of IPhT (postdocs and senior scientist), and allows to have a flux of students visiting the Institute, it is part of our Scientific animation program.

The program is established after a call for ideas to the members of IPhT, and discussions between the organizers, the scientific council and the direction. We often use the opportunity of the long-term visit of prestigious scientists.

Let us note that since last year some courses are organized jointly by IPhT and IHES.

A bit of history. Our courses (after evaluation of the content) were recognized as courses of the Graduate School ED-107 (most students in theoretical physics in the Great-Paris area were affiliated to this "École doctorale"). Since the merging of this ED with two others to become the ED-PIF (École doctorale physique de la Région Parisienne) our program is considered as "courses validated by the ED-PIF", not courses of the ED-PIF. This does not change anything on a daily basis for the students or for organizing the courses. But the visiting committee may ponder about his fact, in view of the issues raised in our response to the recommendations about Université Paris-Saclay of the previous visiting committee.

For details about the courses, see the dedicated web site : https://courses.ipht.cnrs.fr/

Platforms

As a theory institute, we have no platform or specific equipment (apart from the library).

Parity

Please, describe here the actions taken to address gender issues and support gender equity.

Since a long time, IPhT is concerned about these issues. Rather than words, the number of women hired at IPhT in the last decades testify of the fact that IPhT is probably the theory institute with the highest (although modest) woman/men ratio for researchers in France. We are aware that the global situation is not good. For instance in CNRS, the W/M ratio in theoretical physics is the lowest of all, even worse that in mathematics… We plan to continue our efforts, in particular in trying to make theoretical physics attractive for female students at the master level (this is the crucial point).

In the next "Colloque de l'IPhT" which will take place in October, we have scheduled a "theater animation" dealing with "gender equality, ordinary sexism, gender stereotypes and a-priori… in an academic environment", by the "Théatre à la Carte" company.

Scientific integrity

IPhT follows the rules and benefits from the actions of CEA. They are recalled in the following text :

> « En 2017, l'Administrateur général du CEA a signé la Charte nationale de déontologie des métiers de la recherche s'engageant ainsi à porter une politique d'intégrité scientifique et à la mettre en œuvre, au sein de l'établissement, comme l'ensemble de nos partenaires académiques et de recherche.
>
> Un « référent à l'intégrité scientifique » placé auprès de l'Administrateur général a été nommé en janvier 2018, conformément à la lettre-circulaire du Secrétaire d'Etat à la recherche du 15 mars 2017. Il est chargé de proposer à la direction générale une politique en matière d'intégrité scientifique et de veiller à sa mise en œuvre. Il est membre du Réseau des référents à l'intégrité scientifique et participe à ce titre aux travaux menés en son sein, en liaison avec l'Office français de l'intégrité scientifique.
>
> Le CEA a également signé, en 2007, la Charte européenne du chercheur (à laquelle est associé le Code de conduite pour le recrutement des chercheurs), s'engageant ainsi à promouvoir les bonnes pratiques en termes de recrutement, de conditions d'emploi et de travail des chercheurs.
>
> La direction de la recherche fondamentale a mis en place des interventions de sensibilisation auxquelles participent différents membres de notre unité ont été mises en place lors des séminaires hiérarchiques ou de la formation des nouveaux recrutés par exemple.
>
> Au niveau de l'unité, les étudiants en thèse suivent désormais un module obligatoire sur l'intégrité scientifique au sein de leur école doctorale. L'Université Paris-Saclay organise des journées de sensibilisation/formation à l'intégrité scientifique et à l'éthique de la recherche. Un « référent thèse » a été nommé au sein de notre direction, institut, Department, unité. Il peut contribuer à traiter des cas de suspicions ou de manquement à l'intégrité en lien avec les écoles doctorales.
>
> En matière de prévention, la gestion des données de la recherche, que ce soit via les cahiers de laboratoires ou de l'accès aux données de la recherche, associées aux projets et aux publications, sont important. L'unité suit les recommandations élaborées par la direction en matière de traçabilité et d'archivage des cahiers de laboratoires et des données de la recherche. Une réflexion sur les cahiers de laboratoires électroniques est en cours au niveau de [notre] direction.

L'animation scientifique au sein de l'unité, la présentation par les chercheurs, les thésards et les post-doctorats de leurs résultats de recherche devant l'unité contribuent aux actions de prévention. »

We are also following the similar recommendations of CNRS. The Graduate School ED-PIF organizes also actions for the PHD students and their supervisors.

Health and safety

Please describe here the actions taken to address health and safety issues.

IPhT is hosted in a single building (bâtiment 774) which is part of the "Installation n° 9". All safety and health issues are under the responsibility of - and managed with - the "Chef d'installation" (presently François Daviaud, Head of SPEC).

In 2017, CEA carried out a general survey on psychosocial risks and stress in its units. It followed a regulatory obligation which requires the integration of psychosocial risks into the "Single Professional Risk Assessment Document". We worked with the CEA/Saclay management to have this survey carried out for all members of IPhT (CEA, CNRS, graduate students and postdoctoral researchers). The results of this survey were presented to the staff. The results were considered as "rather good", especially in view of the fact that negative points came mainly from the employers, not from IPhT. We decided the following actions (some just continuations of present actions).

- Presentations of the result of the survey and discussion during the "réunion de rentrée" in October 2017
- Emphasis on psychosocial risks during the annual individual evaluation meeting
- Include in the "plan annuel de formation" formations about management of personal situations
- Discussions in the "conseil de laboratoire"
- Formation session at the next « Colloque de l'IPhT » (see above).

Two "psychosocial risks referents" have been appointed. They are the two deputy directors. They are "contact points" for persons who want to signal or alert about possible risks.

5- SWOT analysis

Please, describe here:

- *the unit or team/theme strengths;*
- *the unit or team/theme weaknesses;*
- *the opportunities;*
- *the risks.*

We are aware that a SWOT analysis is a useful formal tool, but that it necessarily overlooks some of the intricacies of the context and situation at IPhT. We present a global analysis.

Comparing to the similar analysis done five years ago (see previous report) and although IPhT did its best with its available resources to deal with the challenges it had to face, we must say that some of the opportunities turned out to be not so real, and that many of the threats are still there, some much closer. One should note that they have been already emphasized by various evaluation panels, both for IPhT and for fundamental research in CEA (and CNRS). But lets us keep a positive mind and go ahead

STRENGTHS :

- The scientific quality of IPhT researchers and their publications. The Institute is very attractive for French and foreign scientists, students looking for an internship or a thesis and for confirmed researchers.

- The renewal of generations achieved between 1995 and 2010, thanks to quality recruitment, in diversified strategic themes. New flagship topics (string theory, condensed matter physics) contributed to the present thematic spectrum and influence of the Institute. There is now a harmonious conjunction of senior and young senior scientists, leaders in their field and of young researchers with the potential to define the research areas of the future.

- The large number of national and international collaborations.

- A large size for a theoretical physics unit. It allows stimulating and productive exchanges between themes, emergence of collaboration and of multidisciplinary research. It contributes to the high visibility of IPhT.

- The large number of grants, especially of ERC fellowships, 17 cumulative to date, including 5 in progress, which cover broad areas of research. The associated overheads allow us to support the rest of our activities.

- The expertise and "task force" we have developed in order to prepare projects and grants applications.

- A large number of PhD students. Although it is decreasing, and despite the reduction in the number of CFR's, the IPhT manages to maintain a very high recruitment quality.

- The support group is qualified, versatile, efficient and close to the researchers (this last point is crucial)

WEAKNESSES:

- The scientific splitting of the Institute: the tendency to the appearance of groups developing distinct cultures and discussing less and less. This is the price of success, and IPhT must be very vigilant.

- The fall in sustainable financing: they are necessary to maintain the volume and quality of our activities on fundamental problems, sometimes out of fashion and affected by contingent events. This research has often distinguished us in the past.

- The weak level and very low success rate for ANR funding of fundamental research.

- The Institute has already drawn heavily on its ERC scholarship potential. This is a price of success.

- Two speeds/two cultures research gap: The cultural gap between the researchers with big contracts and those who lack of it is widening. Some research themes require a lot of man-power (or rather brain-power…), and a large number of PhDs and postdocs is often a crucial advantage in a globalized context. Other themes, although very sharp and competitive, do not need big funding, but require time, freedom, and opportunities for exchanges (invitations of collaborators, conferences).

- Increasingly numerous, complex and demanding administrative tasks. This is due to the multiplicity of funding sources and the various administrative statuses of our visitors, but also to the increasing complexity of the administrative and financial processes.

- The lack of possibility to have researchers with teaching position hired at IPhT, or becoming members of IPhT. With this this respect, the University Paris-Saclay project has been very disappointing up to now.

OPPORTUNITIES:

- The new organization of DRF: It allows already contacts and common projects within DRF with some life sciences institutes and the climate science institute. This is something which will be pushed forwards (and with physical sciences teams as well, of course).

- The Paris-Saclay University: We still hope that the involvement of IPhT will increase our visibility and our attractiveness at the local level, with easier access to teaching, as well as a springboard for a better visibility of the courses of the IPhT on the Paris region. We hope to accommodate colleagues (CNRS researchers or university researchers) from neighboring institutes.

- The Labex: They are a notable source of funding and they have increased and should continue to increase our interactions with the surrounding laboratories and research teams.

- New sources of funding: our researchers remain on the lookout and respond effectively, especially internationally in the niche of private sponsorship (Templeton American Scholarship, Simons Foundation).

- CNRS affiliation: Thanks to our UMR status, the possibility of recruiting and bringing in CNRS researchers is invaluable.

THREATS :

- The non-renewal of generations. The pension legislation and its implementation in CEA presently allow our senior researchers to stay on permanent positions without age limitation. Although IPhT has an active policy of allowing retired researchers to stay (as long as they wished and had a scientific productive activity), this incentive will be clearly not enough for some… This blocks the possibility of youth recruitment and thematic renewal. This is a very serious problem, especially for IPhT. It berates any serious scientific policy. An ageing institute is never attractive for young people, and becomes quickly less competitive. This issue must be addressed by CEA.

- The steady decline in perennial CEA funding, which no longer covers our incompressible expenses (salaries of permanent researchers, infrastructure, services). This funding cannot be entirely replaced by funding by projects, which are increasingly targeted and have a low success rate. This lack of proper resources reduces the attractiveness of the Institute, especially for young researchers.

- The reduction of the number of CFR's, and their targeting on predetermined subjects. It may lead to a drop in applications from very good PhD students, who contribute to the quality of the research carried out in the Institute, to their disseminations once their thesis is completed, and to the visibility of the CEA.

- The relocation of the bests. They are tempted to spend more and more time outside. This trend might in the future be favored by the Labex, (or poorly though reorganizations), which induce a risk of "dilution of IPhT" in large structures, not adapted to our specificity and our modes of productivity.

- The brain drain of CEA researchers: We live now (for the better and for the worst) in a very open, global and competitive scientific environment. Our best researchers are more and more under external solicitations. One of our very best researchers is just leaving for a prestigious position in Paris-Centre. Of course, IPhT is not a fortress and has a very long tradition of people leaving Saclay, nurturing the theoretical physics community. As long as this outward flux in compensated by an inward flux of young and promising scientists this is positive. But as argued above, we are not really in this context anymore.

- The brain drain of CNRS researchers: The risk of departure of CNRS physicists, who are subject to the same solicitations, and by their status, mobile, is even greater. We have lost two of our very good CNRS junior researchers in the last period.

6- Scientific strategy and projects

Please describe and discuss here the future organization, the scientific strategy, the scientific objectives, the resources for achieving them, the partnerships, the new scientific themes, etc.

Organization:

We feel no need to change the present organisation of the Institute. Structure in "groups" is flexible and satisfactory at the moment. It can evolve easily through internal discussions via the scientific council.

The organization of management and technical staff is efficient. We hope it will be maintained.

Projects:

It might make sense to discuss projects and overall goals before discussing strategy.

As stated already in the previous report, it is not a straightforward task to identify a project for IPhT for the next five years, beyond the "dedication to high quality academic research". The spectrum of theoretical physics studied at the Institute is broad, and though each permanent member has a personal scientific project, integrating them all into a coherent collective project is unrealistic and counterproductive. IPHT had - and plans to keep - a pragmatic attitude, and to rely on the inventiveness and the dedication of its researchers to stay a leading institution in theoretical physics.

A conclusive evidence of this fact is that many of the research themes highlighted in the previous report are still highlighted in this report: mathematical physics and integrable systems, string theory and gravitational physics, astroparticles, hadronic matter and QCD, disordered systems, etc. This is not a sign of stagnation, but reflects the fact that research in these themes goes on fast, with often real breakthroughs, and that IPhT keeps its rank !

However, it is also our duty to identify some themes which are developing fast, are promising, and of course which are not driving IPhT away from the research themes and the other laboratories of DRF and of the local environment (unless there is a very strong reason). Here are examples of directions which have to be considered.

The theme of cosmology and particle physics is both structured around large scale experimental and observational projects, and around conceptual issues. It is clear that effort must be pursued in this field. The detection of gravitational waves and the birth of gravitational astronomy for instance is a fantastic opportunity both for our theoreticians for the experimental physicists and astrophysicists of DRF, and this should not be missed.

The general theme of statistical physics and condensed matter is very diverse and developing in several directions. Some seemingly fundamental problems are experiencing great advances: for instance, strong out of equilibrium systems or conformally invariant critical systems in D>2 dimensions (we might have missed some opportunity here). But statistical physics is now also a very powerful set of tools and ideas, with applications to very diverse fields, from social sciences, information sciences, statistical inference, big data and deep learning to biophysics through active matter, the chemical-physics of biomolecules and up to neurosciences. IPhT should be careful to not let these themes to escape. IPhT has already some expertise (notable for some of these subjects) and must seize opportunities.

Condensed matter is now an established subject at IPhT, but one must be careful not letting it diminish by some untimely departures. One important aspects of condensed matter physics is the importance of advanced calculational methods. If the access to massively parallel computer resources is crucial, this should not hide the need of human and computer resources to develop high-end adaptable codes relying on the latest advances of algorithmic, computer sciences and theoretical physics. This has to be considered in the short term.

A not unrelated theme is quantum systems and quantum information. IPhT has many researchers interested in problems connected to this field, but has the capability to develop more in this direction and to attract some promising young researchers.

Going back to mathematical physics, it is doing very well at IPhT, but one concern is that no young researcher has been hired (CEA and CNRS as well) since a long time, while both its scope of application in physics and its relations with the mathematics community are growing. It would be a mistake to let this continue for too long.

Another goal, unfortunately not so easy to achieve, is to be more involved and recognised in the teaching activities of Université Paris-Saclay.

Developing outreach activities is important both for IPhT, and for the image and the status of theoretical physics in the Paris-Saclay project.

Strategy

Though strategy is of crucial importance especially in difficult periods like the one we face today, the room for manoeuvre is minimal.

Unless the perennial CEA and CNRS funding increases in the near future, they cannot be used as a way to develop an autonomous scientific policy. The same can be said for CEA CFR (PHD grants).

Recruitments is the main tool for developing our projects, but they still are the main black spot. As already discussed above, if no positions are available because of the absence of retirements of CEA researchers, IPhT will be in a very poor situation, and this will send a very bad signal to the young generations. Of course IPhT is committed to keep offering our "seniors" a place at IPhT, as we did in the times of the "Accords Capron" when the retirement age was 60 !

We have to keep on relying on external funding agencies and the funding sources of Université Paris-Saclay, by developing our experience and our dynamics, and encouraging and helping our researchers (in particular the young ones) to apply. Favouring targeted mobility towards IPhT has also to be done.

Developing contacts, and when possible collaborations inside DRF and CEA and within the Paris-Saclay research community is one of our goal. The internal visiting program and our involvement in the Institut Pascal (IPa) activities are first steps that should be implemented.

Having our teaching activities recognized and being more involved in the teaching projects of UPSay cannot be done alone. Other labs in DRF are in the same situation and a concerted effort, with support from CEA, should be the right way to proceed.

Developing our relationship with mathematics can be done by getting and exchanging positions. With this respect, mathematicians might be more open than some physicists… We plan for instance to keep developing our relations with IHES.

Some of our projects can obviously be developed by concerted operations, in particular recruitments, with other institutes of CEA.

One should encourage our researchers to participate more to outreach activities, for instance to the "Fêtes de la Science" programs. There are examples (for instance in Canada) that theoretical physics is very attractive to the public, when it is well sold!

And of course, nothing will be possible without maintaining a collective spirit at IPhT. This is what made the strength of "Saclay Theory" since decades. This requires keeping an active scientific animation program, and the good will of everybody!

Appendices

Organization chart

120 personnes - 56 permanents : 2/3 CEA ; 1/3 CNRS

Institut de Physique Théorique (UMR 3681)

François DAVID
Chef de l'Institut de Physique Théorique

Sylvie ZAFFANELLA - Assistante

Anne ANGLES
Adjointe au chef d'Institut
(administration, budget, sécurité)

GESTIONNAIRES		***Laure Sauboy*** *Stagiaires, thésards,visiteurs courte durée, cartes de cantine, comptes WIFI, logistique des conférences, contrats de cession de portables, Association Pour la Science*
		Sylvie Zaffanella *Missions, gestion du personnel permanent, commandes, Postdocs, visiteurs longue durée (binôme avec Carine Roger Roulling)*
		Carine Roger Roulling *(binôme avec Sylvie Zaffanella)* *Missions CNRS, commandes CNRS, et recrutements CNRS (suivi ANR, ERC) / CEA (Postdocs, visiteurs longue durée)* *Correspondante formation et communication CNRS*
INFORMATIQUUE		***Patrick Berthelot*** *Informaticien*
		Laurent Sengmanivanh *Informaticien*
BIBLIOTHUQUE LOGISTIQUE		***Loïc Bervas*** *Informatique : achats, stocks*
		Emmanuelle de Laborderie *Documentation- IST -Base de publications - aide à la communication CEA*

François GELIS
Adjoint au chef d'Institut
(affaires scientifiques, lien avec écoles doctorales, étudiants, rapport d'activité)

Responsable du groupe « Physique mathématique » : **Mariana GRANA**
Responsable du groupe « Particules et Astrophysique » : **Stéphane LAVIGNAC**
Responsable du groupe « Physique Statistique et Matière Condensée » : **Cristina BENA**

Représentant au conseil d'unité : **Filippo VERNIZZI**
Assistant sécurité systèmes d'exploitation : **Laurent SENGMANIVANH**
Animateur sécurité : **Patrick BERTHELOT**
Correspondant communication : **Carine ROGER ROULLING**
Correspondant de formation CEA: **Anne ANGLES**
Correspondants de formation CNRS : **Carine ROGER ROULLING**

References

[t13/019] P. Vanhove, N.E.J. Bjerrum-Bohr, and John Donoghue. On-shell techniques and universal results in quantum gravity. *JHEP*, 02-2014:111, 2014.

[t13/022] M. Cirelli, E. Del Nobile, and P. Panci. Tools for model-independent bounds in direct dark matter searches. *JCAP*, 1310:019, 2013.

[t13/038] J.-P. Blaizot, E. Iancu, and Y. Mehtar-Tani. Medium-induced qcd cascade: democratic branching and wave turbulence. *Phys. Rev. Lett.*, 111:052001, 2013.

[t13/040] P. baratella, M. Cirelli, J. Pata, and A. Strumia. Pppc 4 dmnu: A poor particle physicist cookbook for neutrinos from dm annihilations in the sun. *JCAP*, 1403:053, 2013.

[t13/043] J.T. Liu and R. Minasian. Higher-derivative couplings in string theory: dualities and the b-field. 2013.

[t13/055] M. Graña, D. Marques, Alejandro Rosabal, and Gerardo Aldazabal. Extended geometry and gauged maximal supergravity. *JHEP*, 1306:046, 2013.

[t13/059] G. Gibbons and N.P. Warner. Global structure of five-dimensional bps fuzzballs. *Class. Quantum Grav.*, 32-2:025016, 2013.

[t13/079] I. Bena, J. Blaback, U.H. Danielsson, and T. Van Riet. Antibranes don't go black. *Phys. Rev. D (submitted)*, 2013.

[t13/114] Z. Bern, L.J. Dixon, F. Febres Cordero, S. Hoeche, H. Ita, D.A. Kosower, D. Maitre, and J. Ozeren K. Next-to-leading order w + 5-jet production at the lhc. *Phys. Rev. D*, 88:014025, 2013.

[t13/129] B. Efetov K., H. Meier, and C. Pépin. Pseudogap state from quantum criticality. *Nature Phys.*, 9:442–446, 2013.

[t13/135] P. Valageas, T. Nishimichi, and A. Taruya. Matter power spectrum from a lagrangian-space regularization of perturbation theory. *Phys. Rev. D*, 87:083522, 2013.

[t13/136] P. Brax and P. Valageas. Impact on the power spectrum of screening in modified gravity scenarios. *Phys. Rev. D*, 88:023527, 2013.

[t13/148] S. Nonnenmacher and M. Zworski. Decay of correlations for normally hyperbolic trapping. 2013.

[t13/152] F. Krzakala, C. Moore, E. Mossel, J. Neeman, A. Sly, L. Zdeborova, and P. Zhang. Spectral redemption: clustering sparse networks. *PNAS*, 110:20935–20940, 2013.

[t13/156] Y. Lokhov, M. Mézard, H. Ohta, and L. Zdeborova. Inferring the origin of an epidemy with dynamic message-passing algorithm. *Phys. Rev. E*, 90:012801, 2014.

[t13/160] F. Poitevin, M. Delarue, P. Koehl, H. Orland, and J. Waldispuhl. Computational assembly of polymorphic amyloid fibrils reveals stable aggregates. *Biophys. J.*, 104:683–693, 2013.

[t13/184] R. Louf, P. Jensen, and M. Barthélémy. Emergence of hierarchy in cost-driven growth of spatial networks. *Proc. Nat. Acad. Sci.*, 110:8824–8829, 2013.

[t13/189] F. David and B. Eynard. Planar maps, circle patterns and 2d gravity. *Ann. Inst. Henri Poincaré Comb. Phys. Interact*, 1:139–183, 2014.

[t13/190] F. Gelis and T. Epelbaum. Fluctuations of the initial color fields in high energy heavy ion collisions. *Phys. Rev. D*, 88:085015, 2013.

[t13/191] T. Epelbaum and F. Gelis. Pressure isotropization in high energy heavy ion collisions. *Phys. Rev. Lett.*, 111:232301, 2013.

[t13/198] M. Barthélémy, P. Bordin, H. Berestycki, and M. Gribaudi. Self-organization versus top-down planning in the evolution of a city. *Scientific Report*, 3:2153, 2013.

[t13/204] H. Johansson, D.A. Kosower, and J. Larsen K. Maximal unitarity for the four-mass double box. *Phys. Rev. D*, 89:125010, 2013.

[t13/217] S. Bloch and P. Vanhove. The elliptic dilogarithm for the sunset graph. *Journal of Number Theory*, 148:328, 2015.

[t13/228] Z. Bern, L.J. Dixon, F. Febres Cordero, S. Hoeche, H. Ita, D.A. Kosower, and D. Maitre. Ntuples for nlo events at hadron colliders. *Comput. Phys. Commun.*, 185, 2014.

[t13/264] A.V. Belitsky, S Hohenegger, G. Korchemsky, E. Sokatchev, and A. Zhiboedov. Energy-energy correlations in n=4 sym. *Phys. Rev. Lett.*, 112:071601, 2013.

[t13/265] L. Krapivsky P., J.M. Luck, and K. Mallick. Survival of classical and quantum particles in the presence of traps. *J. Stat. Phys.*, 154:1430–1460, 2014.

[t13/281] M. Bergère, G. Borot, and B. Eynard. Rational differential systems, loop equations, and application to the q-th reductions of kp. 2013.

[t13/287] L. Yan and J.-Y. Ollitrault. Universal fluctuation-driven eccentricities in proton-proton, proton-nucleus and nucleus-nucleus collisions. *Phys. Rev. Lett.*, 112:082301, 2014.

[t13/292] F. Bernardeau, T. Nishimichi, and A. Taruya. Cosmic shear full nulling: sorting out dynamics, geometry and systematics. *Mon. Not. R. Astron. Soc.*, 445 (2):1526–1537, 2014.

[t13/325] T. Sabetta-Penteado and G. Misguich. Nonequilibrium steady states in the quantum xxz spin chain. *Phys. Rev. B*, 88:245114, 2013.

[t13/326] P. Di Francesco. T-systems, networks and dimers. 2014.

[t13/353] R. Louf and M. Barthélémy. Modeling the polycentric transition of cities. *Phys. Rev. Lett.*, 111:198702, 2013.

[t13/385] T. Nishimichi, F. Bernardeau, and A. Taruya. Response function of the large-scale structure of the universe to the small scale inhomogeneities. *Phys. Lett. B*, 09:035, 2013.

[t14/015] P. Vanhove, S. Bloch, and m kerr. A feynman integral via higher normal functions. *Compositio Mathematica*, 151:2329–2375, 2015.

[t14/025] B. Bellazzini, C. Csaba, and J. Serra. Composite higgses. *Eur. Phys. J. C*, 74:2755, 2014.

[t14/029] É. Fusy and E. Guitter. The three-point function of general planar maps. *J. Stat. Mech.*, 2014:09012, 2014.

[t14/033] B. Eynard. An overview of the topological recursion (long version). 2014.

[t14/038] M. Bauer and F. Cornu. Affinity and fluctuations in a mesoscopic noria. *Phys. Rev. A*, 155:703–736, 2014.

[t14/098] L. Krapivsky P., K. Mallick, and T. Sadhu. Large deviations in single file diffusion. *Phys. Rev. Lett.*, 113:078101, 2014.

[t14/105] A. Coimbra, R. Minasian, H. Triendl, and D. Waldram. Generalised geometry for string corrections. *JHEP*, 11:160, 2014.

[t14/108] P. Vanhove, L. Planté, N.E.J. Bjerrum-Bohr, John Donoghue, and B. Holstein. Bending of light in quantum gravity. *Phys. Rev. Lett.*, 114:061301, 2015.

[t14/109] C. Monthus. Low-temperature dynamics of long-ranged spin-glasses : full hierarchy of relaxation times via real-space renormalization. *J. Stat. Mech.*, page P08009, 2014.

[t14/134] E. Vernier, J.L. Jacobsen, and H. Saleur. Non compact conformal field theory and the $a_2^{(2)}$ (izergin-korepin) model in regime iii. *J. Phys. A*, 47:285202, 2014.

[t14/146] J. Larkoski, S. Marzani, G. Soyez, and J. Thaler. Soft drop. *JHEP*, 2014:146, 2014.

[t14/163] P. Creminelli, J. Gleyzes, J. Norena, and F. Vernizzi. Resilience of the standard predictions for primordial tensor modes. *Phys. Rev. Lett.*, 113:231301, 2014.

[t14/164] J. Gleyzes, D. Langlois, F. Piazza, and F. Vernizzi. Healthy theories beyond horndeski. *Phys. Rev. Lett.*, 114:211101, 2014.

[t14/170] P. Creminelli, J. Norena, M. Simonovi, and F. Vernizzi. Single-field consistency relations of large scale structure. *JCAP*, 2013:025, 2014.

[t14/172] I. Bena, M. Graña, S. Kuperstein, and S Massai. Giant tachyons in the landscape. *JHEP*, 02:146, 2015.

[t14/173] F. David, A. Kupiainen, R. Rhodes, and V. Vargas. Liouville quantum gravity on the riemann sphere. *Commun. Math. Phys.*, 2014.

[t14/231] Y. Jiang, I.K. Kostov, D. Serban, and A. Petrovskii. String bits and the spin vertex. 2014.

[t14/232] R.S. Bhalerao, J.-Y. Ollitrault, S. Pal, and D. Teaney. Principal component analysis of event-by-event fluctuations. *Phys. Rev. Lett.*, 114:152301, 2015.

[t14/244] A. Taruya, T. Nishimichi, F. Bernardeau, T. Hiramatsu, and K. Koyama. Regularized cosmological power spectrum and correlation function in modified gravity models. 2014.

[t14/263] C. Micheletti, M. Di Stefano, and H. Orland. The unknotted strands of life: knots are very rare in rna structures. 2015.

[t14/272] I. Bena, M. Shigemori, and P.N. Warner. Black-hole entropy from supergravity superstrata states. *JHEP*, 2014:140, 2014.

[t14/297] A. Saade, F. Krzakala, and L. Zdeborova. Spectral clustering of graphs with the bethe hessian. *NIPS*, 27:406–414, 2014.

[t14/298] B. Karrer, M.E.J. Newman, and L. Zdeborova. Percolation on sparse networks. *Phys. Rev. Lett.*, 113:208702, 2014.

[t14/305] J. Gleyzes, D. Langlois, and F. Vernizzi. A unifying description of dark energy. *World Scientific*, 23:1443010, 2015.

[t14/310] G. Borot, B. Eynard, and A. Weisse. Root systems, spectral curves, and analysis of a chern-simons matrix model for seifert fibered spaces. 2015.

[t14/313] P. Charbonneau, J. Kurchan, G. Parisi, P. Urbani, and F. Zamponi. Fractal free energy landscapes in structural glasses. *Nature Communications*, 5:3725, 2014.

[t14/318] G. Biroli and C. Cammarota. Fluctuations and shape of cooperative rearranging regions in glass-forming liquids. *Phys Rev X*, 7:011011, 2017.

[t14/324] A Lazarescu and V. Pasquier. Bethe ansatz and q-operator for the open asep. *J. Phys. A*, 47:29, 2015.

[t14/325] B. Duplantier, J.D. Miller, and S. Sheffield. Liouville quantum gravity as a mating of trees. 2015.

[t14/357] M. Bauer, D. Bernard, and A. Tilloy. Computing the rates of measurement-induced quantum jumps. *J. Phys. A*, 46, 2015.

[t15/015] Li Yan and J.-Y. Ollitrault. v_4, v_5, v_6, v_7: nonlinear hydrodynamic response versus lhc data. *Phys. Lett. B*, 744:82–87, 2015.

[t15/025] S. Lavignac and B. Schmauch. Flavour always matters in scalar triplet leptogenesis. *JHEP*, 2015:124, 2015.

[t15/031] T. Louail, M. Lenormand, M. Picornell, O. Garcia Cantu, R. Herranz, E. Frias, J. Ramasco, and M. Barthélémy. Uncovering the spatial structure of mobility networks. *Nature Communications*, 6:6007, 2015.

[t15/033] M. Schiro, C. Joshi, M. Bordyuh, R. Fazio, J. Keeling, and H.E. Türeci. Exotic attractors of the non-equilibrium rabi-hubbard model. *Phys. Rev. Lett.*, 116:143603, 2016.

[t15/048] S. Ribault and R. Santachiara. Liouville theory with a central charge less than one. *JHEP*, 1508, 2015.

[t15/051] I. Bena, S. Giusto, R. Russo, M. Shigemori, and P.N. Warner. Habemus superstratum! a constructive proof of the existence of superstrata. *JHEP*, 2015:110, 2015.

[t15/054] A. Barreira, P. Brax, S. Clesse, Li Baojiu, and P. Valageas. K-mouflage gravity models that pass solar system and cosmological constraints. *Phys. Rev. D*, 91:123522, 2015.

[t15/064] E.V. Profumo Rosario, C. Groth, L. Messio, O. Parcollet, and X. Waintal. Quantum monte-carlo for correlated out-of-equilibrium nanoelectronics devices. *Phys. Rev. B*, 91:245154, 2015.

[t15/066] T. Ayral and O. Parcollet. Mott physics and spin fluctuations: a unified framework. *Phys. Rev. B*, 92:115109, 2015.

[t15/073] J.-P. Blaizot and Y. Mehtar-Tani. Jet structure in heavy ion collisions. *Int. J. Mod. Phys. E*, 24:1530012, 2015.

[t15/075] J.-P. Blaizot, D. De Boni, P. Faccioli, and G. Garberoglio. Heavy quark bound states in a quark-gluon plasma: dissociation and recombination. *Nucl. Phys. A*, 946:49–88, 2016.

[t15/081] G. Giesen, M. Boudaud, Y. Genolini, V. Poulin, M. Cirelli, P. Salati, and D. Serpico. Ams-02 antiprotons, at last! secondary astrophysical component and immediate implications for dark matter. *JCAP*, 1509:023, 2015.

[t15/082] M. Dasgupta, R. Dreyer, P. Salam, and G. Soyez. Small-radius jets to all orders in qcd. *JHEP*, 2015:39, 2015.

[t15/087] B. Duplantier, X.H. Ho, and M. Zinsmeister. Logarithmic coefficients and multifractality of whole-plane sle. *Commun. Math. Phys.*, 359:823–868, 2018.

[t15/107] R. Minasian, t pugh, and R. Savelli. F-theory at order α'^3. *JHEP*, 10:050, 2015.

[t15/123] T. Epelbaum, F. Gelis, S. Jeon, G.D. Moore, and B. Wu. Kinetic theory of a longitudinally expanding system of scalar particles. *JHEP*, 2015:117, 2015.

[t15/129] L. Krapivsky P., J.M. Luck, and K. Mallick. Interacting quantum walkers: Two-body bosonic and fermionic bound states. *J. Phys. A*, 48:475301, 2015.

[t15/130] M. Cirelli, T. Hambye, P. Panci, F. Sala, and M. Taoso. Gamma ray tests of minimal dark matter. *JCAP*, 2015.

[t15/135] S. Bloch, m kerr, and P. Vanhove. Local mirror symmetry and the sunset feynman integral. *Adv. Theor. Math. Phys.*, 21:1373–1453, 2017.

[t15/157] E. Tarquini, G. Biroli, and M. Tarzia. Level statistics and localization transitions of lévy matrices. *Phys. Rev. Lett.*, 116:010601, 2016.

[t15/161] B. Bellazzini, Cheung Clifford, and Remmen Grant N. Quantum gravity constraints from unitarity and analyticity. *Phys. Rev. D*, 93:064076, 2016.

[t15/165] D. Gaggero, M. Taoso, A. Urbano, M. Valli, and P. Ullio. Towards a realistic astrophysical interpretation of the galactic center excess. 2015.

[t15/174] A Grozin, M Henn, J, G. Korchemsky, and P Marquard. The three-loop cusp anomalous dimension in qcd and its supersymmetric extensions. *JHEP*, 01:140, 2015.

[t15/182] J.M. Luck. An investigation of equilibration in small quantum systems: the example of a particle in a 1d random potential. *J. Phys. A*, 49:115303, 2016.

[t15/183] I. Bena, M. Graña, S. Kuperstein, Ntokos , and M. Petrini. D3-brane model building and the supertrace rule. 2015.

[t15/188] I. Bena, G. bossard, S. katmadas, and D. Turton. Non-bps multi-bubble microstate geometries. 2015.

[t15/202] Eric D Hoker, M.B. Green, o gurdogan, and P. Vanhove. Modular graph functions. *Commun.Num.Theor.Phys*, 11:165–218, 2017.

[t15/207] G. Le Treut, F. Képès, and H. Orland. Phase behaviour of dna in presence of dna-binding proteins. 2015.

[t15/221] P. Di Francesco and R. Kedem. Difference equations for graded characters from quantum cluster algebra. 2016.

[t15/231] G. Aldazabal, M. Graña, S. Iguri, M. Mayo, C. Nuñez, and Alejandro Rosabal. Enhanced gauge symmetry and winding modes in double field theory. 2016.

[t15/234] N. Crampe, K. Mallick, E. Ragoucy, and M. Vanicat. Inhomogeneous discrete-time exclusion processes. 2015.

[t15/235] F. Bernardeau and P. Flose-Reimberg. A large deviation principle at play in large-scale structure cosmology. 2016.

[t15/241] T. Kloss, X. Montiel, S. Carvalho V., H. Freire, and C. Pépin. Charge orders, magnetism and pairings in the cuprate superconductors. *Rep. Prog. Phys.*, 79:084507, 2016.

[t15/242] T. Kloss, X. Montiel, and C. Pépin. Local particle-hole pair excitations by su(2) symmetry fluctuations. *Scientific Reports*, 7:3477, 2017.

[t15/245] T. Ayral and O. Parcollet. Mott physics and spin fluctuations: a functional viewpoint. *Phys. Rev. B*, 93:235124, 2015.

[t15/249] M. Bauer, D. Bernard, and A. Tilloy. Zooming in on quantum trajectories. *J. Phys. A*, 2016.

[t15/251] C. Caprini. Science with the space-based interferometer elisa. ii: Gravitational waves from cosmological phase transitions. 2016.

[t15/255] S. Franz, G. Parisi, P. Urbani, and F. Zamponi. Universal spectrum of normal modes in low-temperature glasses: an exact solution. *PNAS*, 112, 2015.

[t15/260] Y. Ikhlef, J.L. Jacobsen, and H. Saleur. Three-point functions in c <= 1 liouville theory and conformal loop ensembles. *Phys. Rev. Lett.*, 116:130601, 2017.

[t15/265] J.J.M. Carrasco, R. Kallosh, and A. Linde. Alpha attractors: Planck, lhc and dark energy. *JHEP*, 2015:147, 2015.

[t15/270] M. Rho. The cheshire cat hadrons revisited. 2017.

[t15/271] E. Iancu, J.D. Madrigal-Martinez, A.H. Mueller, G. Soyez, and D.N. Triantafyllopoulos. Resumming double logarithms in the qcd evolution of color dipoles. *Phys. Lett. B*, 744:293–302, 2015.

[t16/012] I. Bena, J Blaback, and D. Turton. Loop corrections to the antibrane potential. 2016.

[t16/015] E. Guitter. Some results on the statistics of hull perimeters in large planar triangulations and quadrangulations. *J. Phys. A*, 49:445203, 2016.

[t16/019] C. Monthus. Many-body localization : construction of the emergent local conserved operators via block real-space renormalization. *J. Stat. Mech.*, 033101, 2016.

[t16/029] Y. Jiang, S. Komatsu, I.K. Kostov, and D. Serban. Clustering and the three-point function. 2016.

[t16/030] B. Bajc, S. Lavignac, and T. Mede. Resurrecting the minimal renormalizable supersymmetric su(5) model. *JHEP*, 2016:044, 2016.

[t16/056] V bouchard. and B. Eynard. Reconstructing wkb from topological recursion. 2016.

[t16/066] T. Ayral and O. Parcollet. Mott physics and collective modes: an atomic approximation of the four-particle irreducible functional. *Phys. Rev. B*, 94:075159, 2016.

[t16/067] I. Bena, S. Giusto, E. Martinec, R. Russo, M Shigemori, D. Turton, and N.P. Warner. Smooth, horizonless geometries deep inside the black-hole regime. 2016.

[t16/069] piotr tourkine and P. Vanhove. Higher-loop amplitude monodromy relations in string and gauge theory. *Phys. Rev. Lett.*, 117:211601, 2016.

[t16/072] G. Giacalone, L. Yan, J. Noronha-Hostler, and J.-Y. Ollitrault. The skewness of elliptic flow fluctuations. *Phys. Rev. C*, 95:014913, 2017.

[t16/078] L.A. Rizzo, F. Mota D., and P. Valageas. Non-zero density-velocity consistency relations for large scale structures. *Phys. Rev. Lett.*, 117:081301, 2016.

[t16/079] P. Brax and P. Valageas. The quantum field theory of k-mouflage. *Phys. Rev. D*, 94:043529, 2016.

[t16/088] C. Monthus. Localization transition in random levy matrices : multifractality of eigenvectors in the localized phase and at criticality. *J. Stat. Mech.*, page 093304, 2016.

[t16/101] L. Daukiya, C. Mattioli, D. Aubel, S. Hajjar-Garreau, F. Vonau, E. Denys, G. Reiter, J. Fransson, E. Perrin, M.L. Bocquet, C. Bena, A. Gourdon, and L. Simon. Covalent functionalization by cycloaddition reactions of pristine, defect-free graphene; acs nano, 2017, 11 (1), pp 627–634. 2016.

[t16/102] Kaladzhyan.V , C. Bena, and P. Simon. Characterizing unconventional superconductors from the spin structure of impurity-induced bound states. *Phys. Rev. B*, 93:214514, 2016.

[t16/119] G. Biroli. Fifth-order susceptibility unveils growth of thermodynamic amorphous order in glass-formers. *Science*, 352-6291:1308–1311, 2016.

[t16/120] M.C. Angelini and G. Biroli. Real space renormalization group theory of disordered models of glasses. *PNAS*, 3328:114, 2016.

[t16/125] J. barbier, M. Dia, N. Macris, F. Krzakala, T. Lesieur, and L. Zdeborova. Mutual information for symmetric rank-one matrix estimation: A proof of the replica formula. *Advanced in Neural Information Processing Systems*, 29:424–432, 2016.

[t16/134] L. Zdeborova and F. Krzakala. Statistical physics of inference: Thresholds and algorithms. *Advances in Physics*, 65 issue 5, 2016.

[t16/141] G. Biroli and P. Urbani. Breakdown of elasticity in amorphous solids. *Nature Phys.*, 12, 2016.

[t16/170] G. Borot, J. Bouttier, and B. Duplantier. Nesting statistics in the $o(n)$ loop model on random planar maps. 2017.

[t16/175] A. Coja-Oghlan, F. Krzakala, W. Perkins, and L. Zdeborova. Information-theoretic thresholds from the cavity method. 2017.

[t16/178] F. Zamponi and P. Urbani. Shear yielding and shear jamming of dense hard sphere glasses. *Phys. Rev. Lett.*, 118:038001, 2017.

[t16/180] G.P. Salam, L. Sarem-Schunk, and G. Soyez. Dichroic subjettiness ratios to distinguish colour flows in boosted boson tagging. *JHEP*, 1703:022, 2017.

[t16/185] R. Couvreur, J.L. Jacobsen, and H. Saleur. Entanglement in non-unitary quantum critical spin chains. 2017.

[t16/191] C. Arita, L. Krapivsky P., and K. Mallick. Variational calculation of transport coefficients in diffusive lattice gases. *Phys. Rev. E*, 95:032121, 2017.

[t16/201] J.J.M. Carrasco, R. Mafra C., and O. Schlotterer. Abelian z-theory: Nlsm amplitudes and alpha'-corrections from the open string. 2017.

[t16/208] S. Nandi, G. Biroli, and G. Tarjus. Spinodals with disorder: from avalanches in random magnets to glassy dynamics. *Phys. Rev. Lett.*, 116:145701, 2017.

[t16/214] M. Delarue, P. Koehl, and H. Orland. Conditioned langevin dynamics enables efficient sampling of transition paths. 2018.

[t16/215] T. Markovitch, D. Andelman, and H. Orland. Ionic profiles close to dielectric discontinuities: Specific ion-surface interactions. *J. Chem. Phys.*, 154:134704, 2016.

[t16/218] Kaladzhyan.V , P. Simon, and C. Bena. Determining the spin-orbit coupling via spin-polarized spectroscopy of magnetic impurities. *Phys. Rev. B*, 94:134511, 2016.

[t16/220] J. Houdayer and F. Poitevin. Reduction of small-angle scattering profiles to finite sets of structural invariants. *Acta Crystallogr. A*, 73:317–332, 2017.

[t16/225] P. Brax. Dark energy and doubly coupled bigravity. *Class. Quantum Grav.*, 34-9:1361–6382, 2018.

[t16/228] J.-P. Blaizot, J. Liao, and Y. Mehtar-Tani. The thermalization of soft modes in non-expanding isotropic quark gluon plasmas. *Nucl. Phys. A*, 961:37–67, 2017.

[t16/229] J.-P. Blaizot. High gluon densities in heavy ions collisions. *Rep. Prog. Phys.*, 80:032301, 2017.

[t16/236] N. Tamanini, C. Caprini, E. Barausse, A. Sesana, A. Klein, and A. Petiteau. Science with the space-based interferometer elisa. iii: Probing the expansion of the universe using gravitational wave standard sirens. *JCAP*, 04:002, 2016.

[t16/240] M. Barthélémy. *The Structure and Dynamics of Cities: Urban Data Analysis and Theoretical Modeling*. 2016.

[t16/243] E. Iancu, A.H. Mueller, and D.N. Triantafyllopoulos. Cgc factorization for forward particle production in proton-nucleus collisions at next-to-leading order. *JHEP*, 12:041, 2016.

[t17/011] T. Lesieur, F. Krzakala, and L. Zdeborova. Constrained low-rank matrix estimation: Phase transitions, approximate message passing and applications. *J. Stat. Mech.*, 7:073403, 2017.

[t17/014] B. Bellazzini, A. Mariotti, D. Redigolo, F. Sala, and J. Serra. R-axion at colliders. *Phys. Rev. Lett.*, 119:141804, 2017.

[t17/022] C. Monthus. Periodically driven random quantum spin chains : Real-space renormalization for floquet localized phases. *J. Stat. Mech.*, 073301, 2017.

[t17/023] C. Monthus. Dissipative random quantum spin chain with boundary-driving and bulk-dephasing: magnetization and current statistics in the non-equilibrium-steady-state. *J. Stat. Mech.*, 043302, 2017.

[t17/024] C. Monthus. Boundary-driven lindblad dynamics of random quantum spin chains : strong disorder approach for the relaxation, the steady state and the current. *J. Stat. Mech.*, 043303, 2017.

[t17/025] I Melnikov, R. Minasian, and S Sethi. Non-duality in three dimensions. *JHEP*, 10:053, 2017.

[t17/029] T. Innamura, K. Mallick, and T. Sasamoto. Large deviations of a tracer in the symmetric exclusion process. 2017.

[t17/030] A. Voros. Discretized keiper/li approach to the riemann hypothesis. 2018.

[t17/031] E. Guitter. On a conjecture by chapuy about voronoi cells in large maps. *J. Stat. Mech.*, page 103401, 2017.

[t17/043] M. Rho. "mass without mass" and nuclear matter. 2017.

[t17/048] C. Godrèche and J.-M. Drouffe. Coarsening dynamics of zero-range processes. *J. Phys. A*, 50:015005, 2017.

[t17/049] C. Godrèche, S.N. Majumdar, and G. Schehr. Record statistics of a strongly correlated time series: random walks and lévy flights. *J. Phys. A*, 50:333001, 2017.

[t17/055] A.N. Efremov, R. Guida, and C. Kopper. Renormalization of su(2) yang–mills theory with flow equations. *J. Math. Phys.*, 58:093503, 2017.

[t17/068] A. Billoire, L.A. Fernandez, A. Maiorano, E. Marinari, V Martin-Mayor, J. Moreno-Gordo, G. Parisi, F. Ricci-Tersenghi, and J Ruiz-Lorenzo. Numerical construction of the aizenman-wehr metastate. *Phys. Rev. Lett.*, 119:037203, 2017.

[t17/070] C. Godrèche and J.M. Luck. Generic phase coexistence in the totally asymmetric kinetic ising model. *J. Stat. Mech.*, page 073208, 2017.

[t17/080] Z. Bern, J.J.M. Carrasco, M. Chen W., H. Johansson, and R. Roiban. Gravity amplitudes as generalized double copies. *Phys Rev X*, 118:181602, 2017.

[t17/083] F. Gelis. Tree-level correlations in the strong field regime. *JHEP*, 1709:055, 2017.

[t17/093] S Tsutsui, J.-P. Blaizot, and Y. Hatta. Thermalization of overpopulated systems in the 2pi formalism. *Phys. Rev. D*, 96:036004, 2017.

[t17/096] C. Aron, G. Biroli, and L.F. Gugliandolo. (non) equilibrium dynamics: a (broken) symmetry of the keldysh generating functional. *SciPost*, 4:008, 2018.

[t17/104] T. Ayral, J. Vucicevic, and O. Parcollet. The fierz convergence criterion: a controlled approach to strongly-interacting systems with small embedded clusters. *Phys. Rev. B*, 96:104504, 2017.

[t17/105] J. Vucicevic, T. Ayral, and O. Parcollet. Trilex and gw +edmft approach to d -wave superconductivity in the hubbard model. *Phys. Rev. B*, 96:104504, 2017.

[t17/108] T. Lesieur, L. Miolane, M. Lelarge, F. Krzakala, and L. Zdeborova. Statistical and computational phase transitions in spiked tensor estimation. *ISIT*, page 8006580, 2017.

[t17/114] W.G. Paeng, T.T.S. Kuo, H.-K. Lee, Y.L. Ma, and M. Rho. Scale-invariant hidden local symmetry, topology change and dense baryonic matter ii. 2017.

[t17/130] L. Chen, N. Curien, and P. Maillard. The perimeter cascade in critical boltzmann quadrangulations decorated by an o(n) loop model. 2017.

[t17/147] D. Beliaev, B. Duplantier, and M. Zinsmeister. Integral means spectrum of whole-plane sle. *Commun. Math. Phys.*, 353:119–133, 2017.

[t17/151] B. Bellazzini, F. Riva, J. Serra, and F. Sgarlata. Beyond positivity bounds and the fate of massive gravity. *Phys. Rev. Lett.*, 120:161101, 2017.

[t17/159] L. Krapivsky P., J.M. Luck, and K. Mallick. Quantum return probability of a system of n non-interacting lattice fermions. *J. Stat. Mech.*, page 023104, 2018.

[t17/161] H. Barbosa-Filio, M. Barthélémy, G. Ghoshal, C. James, M. Lenormand, T. Louail, R. Menezes, J. Ramasco, F. Simini, and M. Tomasini. Human mobility: Models and applications. 2017.

[t17/169] C. Bena. Testing the formation of majorana states using the majorana polarization. *C.R. Physique*, 18:349–357, 2017.

[t17/190] J.-P. Blaizot and M.A. Escobedo-Espinosa. Quantum and classical dynamics of heavy quarks in a quark-gluon plasma. 2017.

[t17/199] Z. Bern, J.J.M. Carrasco, W.-M. Chen, H. Johansson, R. Roiban, and M. Zeng. The five-loop four-point integrand of n=8 supergravity as a generalized double copy. *Phys. Rev. D*, 96:126012, 2018.

[t17/203] S. Migliaccio and S. Ribault. The analytic bootstrap equations of non-diagonal two-dimensional cft. 2018.

[t17/205] G. Misguich, K. Mallick, and L. Krapivsky P. Dynamics of the spin-1/2 heisenberg chain initialized in a domain-wall state. *Phys. Rev. B*, 96:195151, 2017.

[t17/206] P. Creminelli and F. Vernizzi. Dark energy after gw170817 and grb170817a. *Phys. Rev. Lett.*, 119, 2017.

[t17/214] G. Erdemci-Tandogan, H. Orland, and R. Zandi. Rna base pairing determines the conformations of rna inside spherical viruses. *Phys. Rev. Lett.*, 119:188102, 2017.

[t17/215] C. Micheletti and H. Orland. Efficient sampling of knotting-unknotting pathways for semiflexible gaussian chains. *Polymers*, 9:196, 2017.

[t17/216] C. Morice, D. Chakraborty, X. Montiel, and C. Pépin. Pseudo-spin skyrmions in the phase diagram of cuprate superconductors. 2017.

[t17/218] M. Schiro. Time evolution of many-body localized systems with the flow equation approach. *Phys. Rev. B*, 97:060201, 2018.

[t17/220] A.M. Gainutdinov, J.L. Jacobsen, and H. Saleur. A fusion for the periodic temperley-lieb algebra and its continuum limit. 2018.

[t17/232] M. Guica. An integrable lorentz-breaking deformation of two-dimensional cfts. 2018.

[t18/014] C. Monthus. Strong disorder real-space renormalization for the many-body-localized phase of random majorana models. *J. Phys. A*, 51:115304, 2018.

[t18/016] P. Caucal, E. Iancu, A.H. Mueller, and G. Soyez. Vacuum-like jet fragmentation in a dense qcd medium. 2018.

[t18/020] F. Peronaci, M. Schiro, and O. Parcollet. Resonant thermalization of periodically driven strongly correlated electrons. *Phys. Rev. Lett.*, 120:197601, 2018.

[t18/024] Z. Bern, J.J.M. Carrasco, W.-M. Chen, Edison A., H. Johansson, Parra-Martinez Julio, R. Roiban, and M. Zeng. Ultraviolet properties of $n = 8$ supergravity at five loops. 2018.

[t18/029] O. Babelon, K. Kozlowski K., and V. Pasquier. Baxter operator and baxter equation for q-toda and toda_2 chains. 2018.

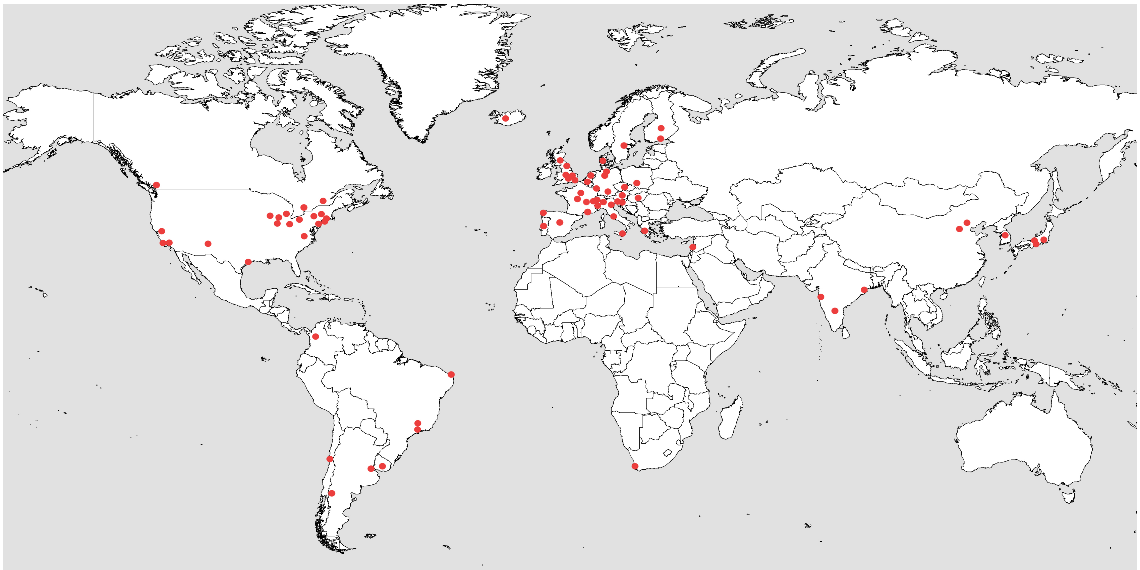
[t18/031] Y. Akrami, P. Brax, A.C. Davis, and V. Vardanyan. Neutron star merger gw170817 strongly constrains doubly-coupled bigravity. 2018.

[t18/046] D.A. Kosower. Direct solution of integration-by-parts systems. 2018.

[t18/075] J. Despersin and M. Barthélémy. *From global scaling to the dynamics of individual cities*, volume 115-10 of *PNAS*. 2018.

[t18/076] M. Barthélémy. *Morphogenesis of Spatial Networks*. Springer Verlag, 2018.

Collaborations



- **France**
  LPT Orsay, LPTMS, IHES, E. Polytechnique, LPTMC, LPT-ENS, LPTHE, LPNHE, IRFU/DPhP, Dpt. Math ENS, IRIF, LPMA, U. Paris-Est, Paris Dauphine, U. Orléans, ENS Lyon, Institut Pasteur, Genopole, U. Grenoble, U. Marseille

- **Americas**
  USA: KITP, UC Santa Barbara, UC Davis, UC Berkeley, LBNL, BNL, Washington U.,Indiana U., U. Southern California, Caltech, Santa Fe Institute, U. of New Mexico, Washington U. in Saint Louis, Colorado Star U., U. of Illinois, U. of Chicago, U. of Michigan, OSU, Rice U., Houston U., Virginia Politechnic Institute, Duke U., Rutgers, Columbia U., NYU, Princeton U., SUNY Stony Brook, Cornell U., Argonne U., Boston U., Yale U., Syracuse U., U. Mass., Carnegie Mellon U., Georgia U.
  Canada: McGill U., Toronto U., U. of Montreal, CRM, U. of Vancouver
  Chile: U. Federal Santa Maria
  Colombia: Universidad de los Andes
  Uruguay: Montevideo U.
  Brazil: U. Alfenas, U. Sao Paulo, IIP Natal
  Argentina: U. of Buenos Aires, U. of Bariloche

- **Asia**
  Korea: KIAS, Hanyang U.
  China: Chinese Acad. Sci. U., CSRC Beijing
  Japan: Tokyo Tech. Inst., U. Tokyo, Osaka U., Doshisha U., Ochanomizu U., YITP Kyoto, RIKEN Nishina
  India: Bose Center Calcutta, TIFR Mumbai, IISR Pune, IIS Bangalore

- **Europe**
  Denmark: Niels Bohr Institute
  Finland: U. of Helsinki, U. of Jyvaskyla
  Iceland: U. of Iceland
  UK: DAMPT, Cambridge, Cambridge U., U. of Sheffield, U. of durham, U. of Nottingham, U. of Glasgow, U. of Edinburgh, U. of Oxford, U. of Sussex, U. of Portsmouth, U. of Birmingham, U. of Southampton, Queen Mary U. U. of Canterbury, Imperial College
  Belgium: VUB, ULB, Leuven U., U. of Namur
  Austria: U. of Vienna, IST
  Greece: U. of Patras
  Netherlands: U. of Leiden
  Switzerland: CERN, EPFL
  Hungary: Wigner Research Centre for Physics, Szeged U.
  Czech Republic: Charles U. Prague
  Slovenia: Jozef Stefan Institute
  Spain: U. of Santiago de Compostela, U. autonoma de Madrid
  Portugal: U. of Lisbon
  Poland: Krakow INP, Jagiellonian U.
  Sweden: KTH-Royal Institute of Technology, Uppsala U.
  Italy: U. of Catania, U. of Padova, U. of Milano Biccoca, U. Sapienza di Roma, ECT* Trento, SISSA Trieste, Politecnico di Torino
  Germany: U. of Karlsruhe, TUM, Goethe U. Frankfurt, DESY, U. of Hamburg, MPI Munich, MPI Bonn, Leibnitz U. Hannover, U. des Saarlandes
  Israel: Tel Aviv U., Ben Gurion U. of the Negev

- **Africa** *South Africa*: U. of Capetown

Prizes, Awards

- *L. Zdeborova*: Philippe Meyer prize in theoretical physics awarded by ENS Paris, 2016
- *L. Zdeborova*: Bronze medal of CNRS, 2014
- *R. Minasian*: KIAS scholar, 2015
- *F. Gelis*: Langevin prize of the SFP, 2015
- *P. Vanhove*: Elected foreign member of the Churchill College, Cambridge, 2015
- *P. Vanhove*: Grand Prix Mergier-Bourdeix of the Académie des Sciences, 2013
- *G. Soyez*: Thibaud Prize (Académie des Sciences, Belles Lettres et Arts de Lyon), 2016
- *C. Bena*: Prize Anatole and Suzanne Abragam of the Académie des Sciences, 2016
- *B. Eynard*: Chaire Aisenstadt 2015-2016, CRM Montreal, Canada
- *C. Pépin*: Emmy Noether Fellow of the Perimeter Institute, 2014

Books

- **String Theory compactifications**, Springer Briefs in Physics (2017), *M. Graña and H. Triendl*
- **Statistical Physics, Optimization, Inference, and Message-Passing Algorithms**, Lecture Notes of the Les Houches School of Physics (special issue, 2013), *L. Zdeborova*
- **String-Math 2016**, Proceedings of Symposia in Pure Mathematics, (2018), *A. Kashani-Poor, R. Minasian, N. Nekrasov, and B. Pioline*
- **Les imaginaires en géométrie**, Zones Sensibles (2016), *P. Vanhove*
- **The formalisms of quantum mechanics, an introduction**, Springer Lectures Notes in Physics (2015), *F. David*
- **Counting surfaces**, Birkhauser (2016), *B. Eynard*

Software packages

- **BPtomo**: https://github.com/eddam/bp-for-tomo, BSD licence *(L. Zdeborova)*
- **MODE-NET**: http://mode_net.krzakala.org, openly shared *(L. Zdeborova)*
- **LowRAMP**: http://krzakala.github.io/LowRAMP, free on github *(L. Zdeborova)*
- **SwAMP**: https://github.com/eric-tramel/SwAMP-Demo, free on github *(L. Zdeborova)*
- **macbeth**: https://github.com/alaa-saade/macbeth_julia, free on github *(L. Zdeborova)*
- **dnner**: https://github.com/sphinxteam/dnner, free on github *(L. Zdeborova)*
- **FastJet**: http://www.fastjet.fr/, GNU Public License *(G. Soyez)*

Conferences organized by IPhT members

- **2013**
  - **Czech workshop on Complex System**, CE-ITI MFF UK, Prague, 3-4 June 2013 *(L. Zdeborova)*
  - **h3QCD (high energy, high density and hot QCD)**, ECT*, Trento, 17-21 June 2013 *(F. Gelis and E. Iancu)*
  - **18th Itzykson meeting – Frontiers of String Theory**, IPhT, July 2013 *(I. Bena, M. Graña, R. Minasian and P. Vanhove)*
  - **Jets in Heavy-Ion collisions**, Paris, 4-6 July 2013 *(G. Soyez)*
  - **Higgs Hunting 2013**, Orsay and Paris, 25-27 July 2013 *(S. Lavignac)*
  - **Quantum spin liquids: from theory to numerical simulations**, Trieste, 9-20 September 2013 *(G. Misguich)*
  - **Ecole Joliot-Curie "A colourful journey: from hadrons to quark-gluon plasma"**, Frejus, 29 September - 4 October 2013 *(J.-Y. Ollitrault)*
  - **Les Houches, Statistical physics, Optimization, Inference and Message-Passing algorithms**, Les Houches, September 30 - October 11 2013 *(L. Zdeborova)*
  - **Present and future of 2nd order CMB**, IPhT, 7-8 November 2013 *(F. Vernizzi)*
  - **Workshop GDR ISIS and PHENIX: Analysis and Inference for Networks**, Paris Telecom-Paristech, November 25, 2013 *(L. Zdeborova)*
- **2014**
  - **Rencontres de Physique Statistique**, ESPCI, Paris, January 2014 *(J.-M. Luck)*
  - **Formes automorphes, algèbres de Lie et théorie des cordes**, University Lille I, 3-6 March 2014 *(P. Vanhove)*
  - **Pont Avignon 2014**, Avignon, 14-18 April 2014 *(P. Brax, M. Cirelli and C. Caprini)*
  - **QCD and forward physics at the LHC**, ECT*, Trento, April 2014 *(G. Soyez)*
  - **The Approach to Equilibrium in Strongly Interacting Matter**, Brookhaven National Laboratory, 2-4 April 2014 *(J.-P. Blazot and F. Gelis)*
  - **Doctoral training program "Heavy Ion Collisions : exploring nuclear matter under extreme conditions"**, ECT*, Trento, 7 April - 16 May 2014 *(F. Gelis and J.-Y. Ollitrault)*
  - **From the Planck scale to the electroweak scale (Planck 2014)**, Paris, 26-30 May 2014 *(S. Lavignac and M. Cirelli)*
  - **19th Claude Itzykson meeting – Amplitudes 2014**, IPhT, 10-13 June 2014 *(G. Korchemsky, D. Kosower, D. Serban, and P. Vanhove)*
  - **Annual school of the ITN network "Invisibles"**, Gif-sur-Yvette, 8-13 July 2014 *(S. Lavignac)*
  - **Annual meeting of the ITN network "Invisibles"**, Paris, 14-18 July 2014 *(S. Lavignac)*
  - **International Symposium "Frontiers of Fundamental Physics"**, Marseille, 14-18 July 2014 *(F. Vernizzi)*
  - **Higgs Hunting 2014**, Orsay and Paris, 21-23 July 2014 *(S. Lavignac)*
  - **Quantum criticality in strongly correlated materials**, International Institute of Physics, Natal, Brazil, 20 July 20 - 1st August 2014 *(C. Pépin)*
  - **Spin glass and beyond: an old tool for new problems**, Cargese, 25 August - 6 September 2014 *(L. Zdeborova)*
  - **VolkswagenStiftung "Frontiers in Field and String Theory"**, Erevan, Armenia, September 2014 *(R. Minasian)*

– **Systèmes désordonnés et processus stochastiques**, IHP, Paris, 14-15 October 2014 *(C. Monthus)*

- **2015**
  - **Rencontres de Physique Statistique**, ESPCI, Paris, January 2015 *(J.-M. Luck)*
  - **Random tilings and surfaces**, Institut Henri Poincaré, 28 January 2015 *(J. Bouttier)*
  - **General meeting of the GDR Terascale**, Saclay, 30 March-1st April 2015 *(S. Lavignac)*
  - **Geometric Invariants and Spectral Curves**, Lorentz Center, Leiden, 1-5 June 2015 *(B. Eynard)*
  - **20th Claude Itzykson meeting – Random Surfaces and Random Geometry**, IPhT, 10-12 June 2015 *(J. Bouttier, F. David and B. Eynard)*
  - **Blois 2015**, Corsica, June 2015 *(G. Soyez)*
  - **De Sitter and microstate landscapes in String Theory**, IPhT, June 2015 *(I. Bena, M. Graña and R. Minasian)*
  - **Czech workshop on Complex Systems II**, CE-ITI MFF UK, Prague, 24-25 June 2015 *(L. Zdeborova)*
  - **Random Interfaces and Integrable Probability**, GGI Florence, 22-26 June 2015 *(J. Bouttier)*
  - **Correlations and Fluctuations in p+A and A+A Collisions**, INT, Seattle, 6-31 July 2015 *(J.-Y. Ollitrault)*
  - **Higgs Hunting 2015**, Orsay, 30 July-1st August 2015 *(S. Lavignac)*
  - **Rencontres du Vietnam (Cosmology session)**, Quy Nhon, Vietnam, 16-22 August 2015 *(F. Vernizzi)*
  - **Equilibration mechanisms in Weakly and Strongly Coupled Quantum Field Theory**, INT, Seattle, 3-28 August 2015 *(F. Gelis)*
  - **Poetic 6**, Ecole Polytechnique, September 2015 *(G. Soyez)*
  - **On Recent Progress in Quantum Field Theory and String Theory**, Erevan, Armenia, September 2015 *(R. Minasian)*
  - **Geometry and Dynamics of Quasiperiodic Structures (GeoDyn2015)**, IHP, Paris, 30 November - 1st December 2015 *(J.-M. Luck)*
- **2016**
  - **Rencontres de Physique Statistique**, ESPCI, Paris, January 2016 *(J.-M. Luck)*
  - **MFO Oberwolfach workshop on Topological Recursion and TQFTs**, Oberwolfach, 14-20 february 2016 *(B. Eynard)*
  - **Rencontres de Moriond de Cosmologie**, La Thuile, Italy, 19-26 March 2016 *(F. Vernizzi)*
  - **Mini-school on the mathematics of string theory**, CIRM, Marseille, April 2016 *(R. Minasian)*
  - **The mathematics of string theory**, IHP, Paris, 11 April - 15 July 2016 *(R. Minasian)*
  - **Nonlinear evolution of the large scale scruture of the Universe**, IAP, Paris, 24-26 May 2016 *(F. Bernardeau and P. Valageas)*
  - **Second workshop on string theory and gender**, IHP, Paris, June 2016 *(M. Graña and R. Minasian)*
  - **21st Rencontres Itzykson – Dynamics, disorder and localization in strongly interacting quantum many body systems**, IPhT, 13-15 June 2016 *(G. Biroli, C. Monthus and M. Schiro)*
  - **PSR 2016**, Paris, June 2016 *(G. Soyez)*
  - **String Math 2016**, IHP and Collège de France, Paris, 27 June - 1st July 2016 *(R. Minasian)*

- **AMS Von Neumann Symposium 2016**, Charlotte, USA, 4-8 July 2016 *(B. Eynard)*
- **Inference problems in biology and computer science (Satellite of STATPHYS26)**, Paris, 10-16 July 2016 *(L. Zdeborova)*
- **Higgs Hunting 2016**, Paris, 31 August-2 September 2016 *(S. Lavignac)*
- **Interplay between Particle and Astroparticle Physics (IPA 2016)**, Orsay, 5-9 September 2016 *(S. Lavignac)*
- **School on Quantum integrable systems, conformal field theories and stochastic processes**, Cargèse, 12-25 September 2016 *(J. Bouttier)*
- **Random Geometry and Physics - Second French-Russian Scientific conference**, IHP, Paris,17-21 October 2016 *(P. Vanhove)*
- **Strings and Geometry**, KIAS, Korea, 24-26 October 2016 *(R. Minasian)*

- **2017**
  - **Rencontres de Physique Statistique**, ESPCI, Paris, January 2017 *(J.-M. Luck)*
  - **Winter school on Combinatorics and Interactions**, CIRM, Marseille, 9-13 January 2017 *(J. Bouttier)*
  - **GGI Lectures on the Theory of Fundamental Interactions**, GGI, Florence, 9-27 January 2017 *(B. Bellazzini)*
  - **String Theory and Scattering Amplitudes**, Simons Center for Geometry and Physics (Stony Brook), 9-13 January 2017 *(P. Vanhove)*
  - **Statistical physics, learning, inference and networks**, Les Houches, February 26 - March 3 2017 *(L. Zdeborova)*
  - **Pont Avignon 2017**, Avignon, 24-28 April 2017 *(P. Brax and N. Tamanini)*
  - **Qu'est ce que la gravité?**, IPhT, 9-10 May 2017 *(P. Brax and P. Vanhove)*
  - **Mini-school on Random Maps and the Gaussian Free Field**, Lyon, 15-19 May 2017 *(J. Bouttier)*
  - **22nd Rencontres Itzykson – Manipulation of Simple Quantum Systems**, IPhT, 6-8 June 2017 *(M. Bauer)*
  - **New flows and old black holes : adventures in quantum gravity and holography – A conference in celebration of Nick Warner's 60th birthday**, IPhT, June 2017 *(I. Bena, M. Graña, M. Guica and D. Turton)*
  - **Colloque énergie noire - congrès SFP**, Orsay, 6 July 2017 *(P. Brax)*
  - **Boulder Summer School on Frustrated and Disordered Systems**, Boulder, Colorado, 3-28 July 2017 *(L. Zdeborova)*
  - **Rencontres du Vietnam (Cosmology session)**, Quy Nhon, Vietnam, 9-15 July 2017 *(F. Vernizzi)*
  - **Higgs Hunting 2017**, Orsay and Paris, 17-19 July 2017 *(S. Lavignac)*
  - **Understanding Cosmological Observations**, Benasque, Spain, 28 July - 9 August 2017 *(F. Vernizzi)*
  - **ICTP/ANSEF Summer School in Theoretical physics**, Erevan, Armenia, 21-26 August 2017 *(R. Minasian)*
  - **The Statistical Physics Cornucopia conference to celebrate Marc Mezard's 60th birthday**, Paris, 6-8 September 2017 *(G. Biroli, and L. Zdeborova)*
  - **Czech workshop on Complex Systems III**, CE-ITI and KAM MFF UK, Prague, 21-22 September 2017 *(L. Zdeborova)*
  - **Dark Mod**, IPhT and IAS orsay, 11 September- 6 October 2017 *(P. Brax and P. Valageas)*
  - **Colloque national Dark Energy**, LAL, 11-13 October 2017 *(P. Brax)*
  - **Dark energy in the laboratory**, Lorentz center, Leiden, 13-17 November 2017 *(P. Brax)*

- **2018**
  - **Rencontres de Physique Statistique**, ESPCI, Paris, January 2018 *(J.-M. Luck)*
  - **GGI Lectures on the Theory of Fundamental Interactions**, GGI, Florence, 8-26 February 2018 *(B. Bellazzini)*
  - **Rencontres de Moriond de Cosmologie**, La Thuile, Italy, 17-24 March 2016 *(F. Vernizzi)*
  - **String dualities and geometry**, Centro Atomico Bariloche, Argentina, January 2018 *(M. Graña)*
  - **Euclid Theory Meeting 2018**, IHP, 16-18 April 2018 *(P. Brax and F. Vernizzi)*
  - **Topological phases of matter: from the quantum Hall effect to spin liquids**, IPhT, 11 June - 6 July 2018 *(G. Misguich)*
  - **Quantum Gravity, Strings and Fields**, Cargèse, 18 - 22 June 2018 *(P. Vanhove)*
  - **Boost 2018**, Paris, 16-20 July 2018 *(G. Soyez)*
  - **MIAPP programme "Probing the quark-gluon plasma with collective phenomena and heavy quarks"**, Munich, Allemagne, 27 August - 21 September 2018 *(J.-Y. Ollitrault)*
  - **Hard Probes 2018**, Aix les Bains, October 2018 *(J.-P. Blaizot)*

External scientific consulting

- *P. Brax*: French representative for the Cantata COST program
- *P. Brax*: Member of the scientific council of PNGRAM and PNCG
- *S. Lavignac*: Member of the steering committee of labex P2IO (October 2012 - September 2014)
- *S. Lavignac*: Member of the working group "P2I department" of Paris-Saclay university (October 2014 - June 2016)
- *S. Lavignac*: Member of the consulting committee of sections 29 and 34 at the Université Paris-Sud (since December 2014)
- *M. Graña*: Member of the Committee for the 5-year evaluation of the Astroparticle and Cosmology laboratory (APC) at Paris Diderot University, November 2017
- *M. Graña*: Member of the hiring committee for a junior professor position (MdC) at Ecole Normale Superieure, June 2017
- *M. Graña*: Member of the hiring committee for a professor position at the Astroparticle and Cosmology laboratory (APC) at Paris Diderot University, May 2018
- *M. Graña*: Member of the committee for attribution of Ph.D. fellowships for the "Ecole Doctorale de Physique d'Ile de France", 2018
- *M. Graña*: Member of the Editorial Board of European Physics Journal C
- *L. Zdeborova*: Member of the scientic "bureau" of topic 2 of Labex PALM, since 2016
- *L. Zdeborova*: Member of the steering committee of CNRS Poncelet Laboratory in Moscow, since 2016
- *L. Zdeborova*: Member the scientic committee of GDR PHENIX
- *L. Zdeborova*: Expert for the European Commission H2020 in 2016-2017
- *L. Zdeborova*: Jury for the competition for doctoral contracts of EDPIF 2017
- *L. Zdeborova*: Selection committee for an assistant professor position in LPTMS, Univ. Paris-Sud Orsay in 2018

- *L. Zdeborova*: Editorial board member of: Phys. Rev. X, Phys. Rev. E and J. Phys. A
- *J.-P. Blaizot*: ERC (panel 02) in 2014, 2016, 2018.
- *J.-P. Blaizot*: Member of the scientific council of the Ecole des Houches
- *P. Vanhove*: Member of the local council of Institut Pascal, since 2018
- *P. Vanhove*: Member of the scientific council of the Labex Jacques Hadamard, since 2016
- *P. Vanhove*: Member of the postdoc hiring committee of the Labex Jacques Hadamard, since 2014
- *P. Vanhove*: Member of the scientific council of IHES, until 2015
- *P. Vanhove*: Referee for the ERC, 2015, 2016, 2018
- *P. Vanhove*: Referee for the search committee of an associate director of the "Center for Geometry and Physics" of the "Institute for Basic Science", Korea, 2018
- *G. Soyez*: Member of CNRS National Committee (section 02), 2012-2016
- *J.-M. Luck*: Member of the HCERES committee for the creation of the Laboratoire de Physique et Chimie Théoriques de l'Université de Lorraine, 2016
- *M. Bauer*: Member of the scientific committee of the GT ALEA (CNRS), until 2017
- *F. David*: Member of the administration council of IHP
- *F. Vernizzi*: Board member of LISA France
- *F. Vernizzi*: Member of the scientific council of the GDR "Ondes Gravitationnelles"
- *J.-Y. Ollitrault*: Member of the review committee of ECT*, Trento, Italy, May 2018
- *C. Pépin*: Member of the ANR committee CS30 since 2017
- *C. Pépin*: Physics and Astronomy Panel Member of the The Danish Agency for Science, Technology and Innovation, 2013-2016
- *C. Pépin*: Member of the selection committee of the Chaires d'Excellence Blaise Pascal since 2012
- *C. Pépin*: Member of the hiring committee for a professor, Université de Tours, 2016
- *C. Pépin*: Member of the hiring committee for a professor, Université de Cergy-Pontoise, 2016
- *F. Gelis*: Board member of the ECT*, Trento, 2012-2015
- *F. Gelis*: Member of the external review committee of the CTMP, University of CapeTown, 2014
- *F. Gelis*: Convener for the 2017' NuPECC Long Range Plan