AGENCE NATIONALE DE LA RECHERCHE ANR	**Scientific Report** **January 2017**	INVESTISSEMENTS D'AVENIR

LABEX

CEMPI

1. PROGRESS OF THE PROJECT: AN OVERVIEW

Origins of CEMPI. The ``Laboratoire d'Excellence" CEMPI (Centre Européen pour les Mathématiques, la Physique et leurs interactions), a project of the Laboratoire de Mathématiques Paul Painlevé and the Laboratoire de Physique des Lasers, Atomes et Molécules (PhLAM), was created in the context of the "Programme d'Investissements d'Avenir" in February 2012 and started operations effectively in September of that year. It runs until December 31 2019. The text of the project, as it was proposed in 2012, can be found at the following Internet address:

http://math.univ-lille1.fr/~cempi/files/CEMPI_b_public.pdf.

The goal of the partnership Painlevé-PhLAM through the CEMPI project, and in close collaboration with the Equipex FLUX, is to stimulate fundamental and applied research, as well as training and technological development within a wide spectrum of knowledge stretching from pure and applied mathematics to experimental and applied physics. Emphasis is put on fostering interactions between mathematics and physics, as well as with other sciences such as biology or computer science, and also with technological innovation in fiber optics. Among the three mathematics-physics interaction themes that make up the first focus area of CEMPI, essentially one concerns research carried out at PhLAM, namely complexity in atomic physics and optics, as well as quantum information theory, whereas the two other touch domains of physics studied elsewhere. The other main area of interaction between Painlevé and PhLAM is the "Physics and Mathematics for Biology" focus area. The CEMPI furthermore develops its activities through partnerships with internationally renowned teams in first rate foreign institutes such as the Universities of Bristol and Aberdeen (United Kingdom), Leuven, Louvain-La-Neuve and Photonics@be IAP (Belgium), the Max-Planck Institute in Bonn (Germany), the Fields Institute in Toronto (Canada) and SISSA (Italy).

Evolution since the last report in January 2015. In the following sections, we will describe the activities and results of the CEMPI since the last report, which goes back to January 2015, covering CEMPI's activities between January 2015 and December 2016, in its three fields of action: research, training, technology transfer and economic impact. For many of these activities, details can be found in the different pages of the CEMPI website at http://math.univ-lille1.fr/~cempi. We will also provide information on the CEMPI governance and budget.

As will become apparent in the following pages, after almost five years of operation, all CEMPI programs and actions foreseen in the original project have reached maturity and are fully operational. In addition, by bringing together the strengths of the two main physics and mathematics laboratories of the Université Lille 1, CEMPI has helped to re-structure the scientific landscape on its principal campus, in Villeneuve d'Ascq. Starting in 2012 with two laboratories whose members knew little each

other and were unfamiliar with each other's research, the CEMPI teams have succeeded in creating an effective scientific collaboration whose measurable results are increasingly visible, and continuously evolving, as explained below. CEMPI has also been solicited repeatedly for participation in projects responding to new PIA calls for proposal such as the IDEX UdL (2015), which was preselected but not attributed, the very recently proposed IDEX ULNE (2016), as well as the Convergence Institute REVBIO, which in April 2016 obtained a very positive evaluation (19/20) and was re-submitted in December 2016.

In our 2015 report, we identified a number of actions destined to further develop the CEMPI project. Those were developed in the following manner:

- We have continued our efforts to increase the visibility of our training programme (Master-PhD-Postdoc), which have proven fruitful and to constitute in this manner a CEMPI Graduate School. For more details we refer to Section 1.3.
- The link between CEMPI and the Probability and Statistics research group of the Laboratoire Paul Painlevé have been considerably strengthened over the past two years, as announced in the previous report. In particular, two postdocs were hired with CEMPI funding, as well as one PhD student, and several invited professors. The activities of the 2016 Painlevé-CEMPI-PhLAM Thematic Semester concentrated on themes from probability and statistics, many of an interdisciplinary nature with physics or biology. The third volume of the CEMPI Subseries of LNM will present a collection of introductory courses on random geometry some of which were taught during the semester. As an example of a new research project we mention a statistical description of infinite volume Coulomb gases as canonical Gibbs measures. This project, lead by Prof. D. Dereudre, Prof. A. Hardy and Prof. M. Maida from the Laboratoire P. Painlevé and by Prof. T. Leblé from the Courant Institute in New-York, is well advanced and should provide soon a publication in a high level journal. In addition, a project has been initiated with the physicists from PhLAM in the domains of optical systems and statistical physics. The goal is to investigate a statistical approach to the analysis of rogue waves for non-linear Schrödinger equations with random initial conditions.
- Painlevé researchers of themes 2 (algebraic geometry) and 3 (analysis) of focus area 1 of the project, inspired by the multiplicity of problems related to singularities that arise both in geometry and analysis, have developed since 2015 a common project around this theme. A weekly discussion group and seminar on the theme take place, in which both researchers from Lille and invited speakers intervene. Two workshops, in 2016 and 2017, have been organized as well. In parallel the research activity on quantum information theory, which involves members of the PhLAM and of the analysis team of the Painlevé Laboratory has been further developed.
- CEMPI has recently focused more on its research in geometric group theory, dynamical systems, deformation theory of geometric structures on manifolds, and the dynamical properties of actions of groups. These subjects areas are in part at the center of theme 2 of focus area 3, and for some also have interesting connections with theme 1 of focus area 1. In this context, Fanny Kassel (CR CNRS, Painlevé) obtained the ``Médaille de Bronze'' of the CNRS for her work in 2015, and was awarded an ERC Starting Grant in 2016. For further details, we refer to Section 1.2 and 2.
- The knowledge exchange with theoretical computer scientists, successfully begun with the workshop and series of mini-courses in 2012, has continued. It will culminate with a 5 month programme covering the theme, to be held at the Isaac Newton Institute in Cambridge in January-June 2017, an occasion to consolidate the advances in the area and to chart new directions of research. In particular the fourth workshop of the programme will cover key topics at the interface of geometric group theory and computer science, and counts among its participants major players in the area.

- In the framework of the new Contrat de plan État-Région (CPER, 2015-2020), CEMPI and FLUX have proposed the Photonics4Society project that has been validated by the Region Nord-Pas de Calais

in 2015, for 5M€ and that has been awarded an additional 7M€ by the European Regional Development Fund. It has started its operations in the fall of 2015.

CEMPI research obtained several notable successes in 2015-2016, among which, beyond the Médaille de Bronze and the ERC Starting Grant of Fanny Kassel that were already mentioned:

- Dr. J.C. Garreau (PhLAM) was awarded the 2015 Prix Leconte Prize of the Académie des Sciences, for his work on the Anderson transition in kicked rotor systems.
- Prof. A. Mussot became a Junior Member of the IUF (2015-2018).
- Prof. A. Virelizier (Painlevé) was awarded, together with his co-author, Prof. V. Turaev, the Ferran Sunyer i Balaguer prize 2016, for his monograph "Monoidal categories and topological field theory" in in the Birkhäuser series "Progress in mathematics".
- Two major scientific advances published in the leading open source journals Nature Communications and Cell Reports in october 2016 will be communicated to the general public by the CNRS Institute of Physics in its "Scientific News" newswire.

The midterm evaluation of the Labex CEMPI by the ANR took place in June 2015. It was based on the report we had previously submitted to the CEMPI Scientific Advisory Board and on an interview with an international jury, in which Stephan De Bièvre, Pierre Dèbes and Marc Lefranc presented the Labex CEMPI and answered the jury's questions. The final conclusions of the jury read as follows:

"Overall, LABEX CEMPI is doing a good job in two essential areas. The first area is in making a coordinated effort to get more mathematicians active in interdisciplinary research relevant to local industry and academic laboratories. The second area is in boosting the number of graduate students in their masters program. They are also retaining more masters students to stay for the PhD program. There efforts to engage industry are expected to have a substantive impact on the local economy and help their graduates find mathematically relevant employment.
The LABEX CEMPI is playing an important role in the IDEX Lille bid to unify the universities in the Lille region. We were very impressed that this was the only presentation to include a SWOT analysis."

The complete report of the jury can be found in the Appendix. The jury recommended an effort should be made to further increase the international visibility of CEMPI by encouraging the participation of its members in international conferences. CEMPI earmarked funds specifically for that purpose, directed towards the younger faculty in particular, for whom it is harder to find alternative funding for such purposes.

Looking towards the future. Since it seems in the nature of time to accelerate, January 2020 will soon be here, and signal the end of the CEMPI contract as such. Perceiving, as we do, the many positive effects of the dynamics set up by CEMPI, we have started to prospect ways in which to make them last. More details on those efforts can be found in Section 2.D.

The present report follows the template provided by the ANR for the midterm evaluation of 2015. In the following subsections we give brief assessment of our activities in governance, research, training, result exploitation and outreach and visibility. More details are then provided in the following sections.

1.1 Governance

Already at the time of the 2015 report, all strategic and operational aspects of the project were solidly in place. The following changes occurred since.

In order to take into account the enlargement of the scientific scope of CEMPI with additional themes from analysis, probability and geometry, as decided in the beginning of 2015, the team leaders of the corresponding research groups of the Painlevé Laboratory have been systematically invited to participate in the bi-monthly meetings of the CEMPI Executive Committee.

Prof. B. Perthame (Univ. Paris 6, Pierre et Marie Curie) has accepted to join the CEMPI Scientific Board. His expertise in mathematical biology and more generally in Partial Differential Equations theory and application will be an asset, in particular in designing the future course of the project, beyond 2019.

1.2 Research

The main research ambition of CEMPI, as formulated in the original project, is to stimulate research at the interface of mathematics and physics, in particular to generate collaborations between the two partner laboratories, and, beyond that, to favour interdisciplinary research between mathematics, physics, biology, computer science, on a number of selected topics. The opportunities offered by the creation of CEMPI have been seized enthusiastically and we are realizing this part of the program successfully. In particular, the collaboration between the two partner laboratories is now reaching a state of maturity, with five joint publications involving twelve CEMPI researchers, particularly in Focus Area 1, Themes 1 and 3. Details are provided below and in Section 2. As indicated in the previous section, efforts to enlarge this collaboration base are under way and will lead to further successes in the coming years.

We list here some of the most striking results obtained in 2015-2016, in each of the six CEMPI themes. More details on the CEMPI scientific production are provided in Section 2.A.

FOCUS AREA 1: THE INTERFACE OF MATHEMATICS AND PHYSICS

(1) NONLINEAR COLLECTIVE DYNAMICS IN COMPLEX ATOMIC AND OPTICAL MANY-BODY SYSTEMS: DETERMINISTIC AND STOCHASTIC ASPECTS

This theme has evolved considerably over the period 2015-2016. The subjects covered are topical and some of the work accomplished is the result of an effective collaboration between the partner laboratories that has produced several results in top journals, which could not otherwise have been obtained. We present here four representative highlights of this research.

First, important experimental progress has been obtained in the past two years by developing several ultra-fast detection techniques allowing major experimental advances in the field of statistical nonlinear optics [1]. In particular, we have developed an optical sampling device, which makes it possible to measure, for the first time, the statistical distribution of partially coherent light intensity fluctuations. Another remarkable fact is the realization of a "temporal microscope", which allows to precisely observing the ultra-fast dynamics (at the 250 femtosecond scale) characteristic of the propagation of random waves in an optical fiber.

Second, in [2], a very precise study of the Anderson localization in two-dimensions has been performed, using the quantum kicked rotor as “quantum simulation”, allowing in particular the observation of the cross-over from the 1D to the 2D behavior as a function of a single control parameter. Hamiltonian engineering also allowed a study of the basic interference mechanisms involved in the phenomenon of weak localization and its sensitivity to control decoherence.

Third, a team of mathematicians and physicists of CEMPI investigated the modulation instability process in a new generation of waveguides that are longitudinally and periodically modulated [3]. They showed theoretically and experimentally that new instability bands are destabilized by this periodic variation. They also investigated the nonlinear regime and show that Fermi-Pasta-Ulam recurrence phenomenon should be observed in these fibers. Experiments are being planned to observe it.

Fourth, in a field at the intersection of mathematics and biology, we investigated the numerical

simulation of self-organized dynamics models of swarming and flocking in animal populations through a mean field description, in order to avoid dealing with a large number of individual particles. To improve the long time asymptotics of the numerical solution, this work introduces and analyses a new self-similar scaling as well as new numerical fluxes in order to preserve the mathematical properties of the equation such as mass conservation and flocking dynamics.
Finally, we studied the asymptotic behaviour of eigenvalues of large complex correlated Wishart matrices at the edges of the limiting spectrum. In this setting, the support of the limiting eigenvalue distribution may have several connected components. Under mild conditions for the population matrices, we show that for every generic positive edge of that support, there exists an extremal eigenvalue which converges almost surely toward that edge and fluctuates according to the Tracy-Widom law at the scale N^2/3.

[1] P. Suret, R. El Koussaiffi, A. Tikan, C. Evain, S. Randoux, C. Szwaj and S. Bielawski, *Single-Shot Observation of Optical Rogue Waves in Integrable Turbulence Using Time Microscopy*, Nature Comm. 7, 13136 2016.

[2] I. Manai, J.-F. Clément, R. Chicireanu, C. Hainaut, J. C. Garreau, P. Szriftgiser and D. Delande, *Experimental Observation of Two-Dimensional Anderson Localization with the Atomic Kicked Rotor*, Phys. Rev. Lett. 115, 240603, 2015.

[3] M. Conforti, A. Mussot, A. Kudlinski, S. Rota Nodari, G. Dujardin, S. De Bièvre, et al. *Heteroclinic Structure of Parametric Resonance in the Nonlinear Schrödinger Equation*, Phys. Rev. Lett., 117 (1):013901, 2016.

[4] T. Rey and C. Tan, *An Exact Rescaling Velocity Method for some Kinetic Flocking Models*, SIAM J. Num. Anal. 54(2), pp. 641–664, 2016. DOI 10.1137/140993430.

[5] W. Hachem, A. Hardy, J. Najim, *Large complex correlated Wishart matrices: fluctuations and asymptotic independence at the edges*, Ann. Probab., 44, 3, pp. 2264–2348, 2016, doi:10.1214/15-AOP1022.

(2) ALGEBRAIC GEOMETRY, MODULAR FORMS WITH APPLICATIONS TO PHYSICS

Mladen Dimitrov, jointly with J. Bellaïche [1], showed that the p-adic eigencurve is smooth at classical weight-1 points which are regular at p and gave a precise criterion for étaleness over the weight space at those points. Niels Borne, jointly with A. Vistoli [2], elaborated the concept of ``Nori's fundamental gerbe", a version of Nori's fundamental group scheme without reference point, in view of future applications to the problem of uniformization of algebraic stacks. Pierre Dèbes [3] obtained a negative answer to the strong version of Regular Inverse Galois Problem by proving that for certain finite groups G there is no universal Galois extension of the field of rational functions over Q with group G.

[1] J. Bellaïche, M. Dimitrov, *On the eigencurve at classical weight 1 points*, Duke Math. J. 165 (2016), 245-266.

[2] N. Borne, A.Vistoli, *The Nori fundamental gerbe of a fibered category*, J. Algebraic Geom. 24 (2015), 311-353.

[3] P. Dèbes, *Groups with no parametric Galois realizations*, to appear in Annales de l'Ecole Normale Supérieure, 2016.

(3) OPERATOR ALGEBRAS, HARMONIC ANALYSIS, QUANTUM GROUPS WITH APPLICATIONS TO PHYSICS.

In this theme we chose to highlight results of some of our younger researchers. F. Chabbabi (Painlevé, CEMPI PhD student 2014-2017) gave a complete characterization of bijections that “product-commute” with the λ-Aluthge transform [1]. When T is a bounded operator on a Hilbert space H, its polar decomposition can be written as $T=V|T|$, where V is an appropriate partial isometry and $|T|$ is the square root of T*T. The λ-Aluthge transform of T is then the operator $\Delta_\lambda(T)=|T|^{\lambda}V|T|^{(1-\lambda)}$. This

transform has attracted considerable attention in recent years in connection with . A map Φ from the bounded operators of one Hilbert space H to another Hilbert space K is said to "product commute" with the λ-Aluthge transform when $\Phi(\Delta_\lambda(TS)) = \Delta_\lambda(\Phi(T)\Phi(S))$ for all bounded operators T, S from H to K. Chabbabi proves this can only occur in the case where $\Phi(T)=U^*TU$, for some unitary operator U from K to H.

R. Rupam (Postdoc CEMPI) and E. Fricain (Painlevé) studied the property of asymptotically orthonormal basis, that is basis which satisfy a Parseval equality up to two constants close to one. In terms of the Gram matrix, this is equivalent to say that the Gram matrix is of the form identity plus compact. Using an approach based on the functional model developed by Sz. Nagy-Foias, they gave sufficient conditions which guaranty that an exponential system which forms an asymptotically orthonormal basis is stable under small perturbation of its frequencies. This stability result uses in particular a Bernstein's type inequality recently developed by Baranov-Fricain-Mashreghi in the context of model spaces.

[1] F. Chabbabi, *Product commuting maps with the λ-Aluthge transform,* J.Math. Anal. Appl. http://dx.doi.org/10.1016/j.jmaa.2016.12.027
[2] E. Fricain and R. Rupam, *On asymptotically orthonormal sequences,* preprint 2016, https://arxiv.org/pdf/1605.04387v1.pdf.

FOCUS AREA 2: THE INTERFACE OF PHYSICS AND BIOLOGY

To maintain life, cells orchestrate molecular events in response to external or internal stimuli. To generate these events, biological functions such as the cell division cycle or the circadian clock rely on a network of genes and proteins interacting through feedback loops. These networks are dynamical systems which harness typical nonlinear behaviors such as bistability or oscillation. Deciphering the design principles underlying biological functions thus requires to combine mathematical modeling and dynamical system theory on the one hand, and biophysical/biophotonic approaches to image the dynamics of molecular networks in real time in live cells.
In 2015-2016, three major advances have been achieved in these two areas. (A) Proper tissue development requires that stem/progenitor cells precisely coordinate cell division (to increase the number of cells) and differentiation (to create the various cell types making the tissue) in space and time. A mathematical model of the Notch-Hes1 cellular signaling system controlling cell fate determination in neural progenitors has been constructed and it has been used to explain how proliferation and differentiation are exquisitely coordinated during neural development [1]. (B) The expertise of the biophotonics group in characterizing molecular interactions between proteins inside cells has contributed significantly to a large collaborative work evidencing the anti-cancerous activity of new compounds in melanoma cells [2]. (C) Our lives are governed by an alternation of days and nights, to which our organisms have adapted by developing biological clocks throughout our bodies. A mathematical model of how the liver circadian clock is entrained to the day/night cycle by feeding and fasting cycles has been constructed and has been shown to agree well with experimental data. This model will hopefully help us to understand the role of the clock in diseases such as obesity and diabetes [3].

[1] B. Pfeuty, "A computational model for the coordination of neural progenitor self-renewal and differentiation through Hes1 dynamics", Development 142, 477-485 (2015).
[2] M. Cerezo et al. (with L. Héliot and M. Gonzalez-Pisfil), "Compounds Triggering ER Stress Exert Anti-Melanoma Effects and Overcome BRAF Inhibitor Resistance", Cancer Cell 6, 805-819 (2016).
[3] A. Woller, H. Duez, B. Staels & M. Lefranc, "A Mathematical Model of the Liver Circadian Clock Linking Feeding and Fasting Cycles to Clock Function", Cell Reports 17, 1087 (2016).

FOCUS AREA 3: THE INTERFACE OF MATHEMATICS AND THEORETICAL COMPUTER SCIENCE.

(1) ALGEBRAIC TOPOLOGY, HIGHER CATEGORIES, OPERADS, WITH APPLICATIONS TO THEORETICAL COMPUTER SCIENCE.

In the monograph [1], for which they received the Ferran Sunyer i Balaguer prize 2016, V. Turaev and A. Virelizier focus on monoidal categories and their connection with three-dimensional topological field theories, guiding readers from basic definitions to the forefront of current research. The main result of the monograph says that the state sum TQFT derived from a spherical fusion category is isomorphic to the Reshetikhin-Turaev surgery TQFT derived from the centre of that category.
Chataur-Saralegi-Tanré have discovered an analogue for the Goreski-MacPherson intersection cohomology of pseudo-manifolds of the Sullivan model for the rational homotopy of spaces [2]. One of the significant outcome of their work is the solution of a conjecture of Goreski and MacPherson about the definition of Wu classes in intersection cohomology.

[1] V. Turaev and A. Virelizier, *Monoidal categories and topological field theory,* Birkhäuser Series "Progress in mathematics," 2016.
[2] D. Chataur, M. Saralegi-Aranguren and D. Tanré, *Intersection Cohomology. Simplicial Blow-up and Rational Homotopy*, preprint arXiv:1205.7057 (2012), x+108 pages, http://arxiv.org/abs/1205.7057, Memoirs of the AMS (2017).

(2) GRAPHS AND GROUPS, WITH APPLICATIONS TO THEORETICAL COMPUTER SCIENCE.

Together with Jeffrey Danciger (Austin, Texas), François Guéritaud (Painlevé) and Fanny Kassel (Painlevé) have established a classification of Margulis space-times, i.e. the proper quotients of R^3 by a free group acting affinely on it. The linear part of such an action corresponds always to a hyperbolic surface (Fried-Goldman). Danciger, Guéritaud and Kassel parametrize the translational parts by the complex of the arcs of this surface [1]. This allows them to deduce a series of results on the Margulis space-times: they are topologically handle-bodies, they admit fundamental domains bordered by "crooked planes" (proving a conjecture by Charette, Drumm and Goldman), they admit straight fibrations, etc. [2].
The same authors have been able to generalize some of their ideas to show that every right angles Coxeter group admits a properly discontinuous action on some affine space R^n (until now this was known only for the free group). This implies that the same holds true for all groups admitting a cubulation, in particular for all virtually special groups, for the fundamental groups of 3-hyperbolic manifolds, etc.

[1] J. Danciger, F. Guéritaud and F. Kassel, *Margulis spacetimes via the arc complex*, Inventiones Mathematicae 204, pp 133-193 (2016)
[2] J. Danciger, F. Guéritaud and F. Kassel, *Geometry and topology of complete Lorentz spacetimes of constant curvature"*, Annales scientifiques de l'ENS 49-(1), pp 1-57, 2016.

1.3 Training

The first years: 2012-2016. The training of interdisciplinary scientists from the Masters to the postdoctoral level continues to be an essential part of CEMPI's activities. As detailed on the CEMPI website, four Master's programs are associated to CEMPI. To strengthen these programs through the recruiting of excellent students, CEMPI offers every year a number of Master's fellowships and Master's internships. In addition, CEMPI also proposes several PhD and postdoctoral fellowships every year.

The openings for the positions are announced in the late fall, via the web and through posters sent to over 120 institutions in France and abroad. In addition, the scientists from both laboratories publicize

the openings in their own networks in France and abroad. Since 2014 an announcement was also made every year in the Journal of the AMS. We expect that the number of applicants, which is already quite satisfactory, will continue to rise.

After 4 to 5 years of operation, these programs have proved very successful and changed dramatically the predoc/doc/post-doc situation in our departments. The number of PhD students has considerably increased, our Master's programs have benefited from the good Master's students we have been able to attract and the Post-Doc program has brought to Lille excellent postdocs from outside (where we used to only have local students hired on unattractive teaching assistant positions). Altogether, this has created a critical mass of very good young students/researchers, the **CEMPI Graduate School**, animated by an enthusiastic collective working spirit which benefits both the younger students by providing them guidance in their beginning professional careers, and the senior researchers by strengthening the research teams. The CEMPI Graduate School thus provides the link between the study and the research worlds, which was missing in our departments and which was one main goal of the CEMPI project.

Our flexible system of Master's fellowships has two complementary goals: attract excellent students from other French and foreign universities and keep our top students in our own programs. We offer our Master's fellowships either for the two years M1 and M2 (if results in M1 are satisfactory), or only for the second year M2, depending on the demand and the preparation of the students. In addition, we have financed 14 three to six month Master's internships. At least as many others joined our program with different funding sources. This action revealed very useful: it has allowed us to attract some top students who we then hired for our Ph.D program.

Since September 2012, 43 one-year Master's fellowships (M1 or M2), 21 Ph.D students (each for 3 years) and 13 postdoctoral years have been totally or partially financed by the CEMPI training programs. The following table summarizes the situation.

Fellowships	2012 Number of students hired	2013 Number of students hired	2014 Number of students hired	2015 Number of students hired	2016 Number of students hired	Percentage of funding currently committed
Master's	8	5	13	8	9	80%
PhD	3	3	3	7	5	100%
Postdoc	0	2	3	4	4	150%
Internships	0	8	2	1	3	30%

CEMPI has not only brought its own financial means in these funding operations but has also benefited from a clear leverage with several granting institutions that are generally keen to co-finance our projects. For example, the Région Nord-Pas de Calais has provided some funds in 2013-2015 to finance Master's fellowships. In addition, in most cases, CEMPI only finances half of the total cost of the three-year PhD fellowships; either the Université Lille 1 or the Région Nord-Pas de Calais provides the remaining part of those fellowships. This explains why we have been able to hire 21 PhD students while funding for only 12 full time contracts was provided in the original project. Extra postdoc

funding came through the FEDER and the CPER Photonics for Society. It is then clear that the impact of CEMPI has gone beyond the funding it provides directly.

An quick analysis the professional trajectory of our students and postdocs after they leave CEMPI provides an indication of the quality of our programs. A first clear indicator is that nearly 70% of the CEMPI Master's students started a PhD thesis, in Lille or elsewhere, after completing their Master's degree with us. In addition, 7% entered industry, 7% took up teaching positions, and 7% completed their training with a different Master's degree. The remaining 9% are in search of employment. In addition, out of the 5 postdocs who have completed their stay with us, 3 have been nominated as ``Maître de Conférences'' (in Dijon, Lyon and Paris 6) and 2 have obtained a long term academic position in Germany and Lebanon respectively. Out of the 21 Ph.D students, five have completed their thesis and are pursuing their academic career. These results clearly indicate the international attractivity and the quality of our scientific environment.

The last years: 2017-2019. As announced in our 2015 report, we have started to transfer funding from the ``invited professor'' budget to the ``graduate school'' budget, which has allowed us in particular to hire more postdocs than originally programmed (See table above). Continuing this policy, we expect to hire three more PhD students in 2017 (with partial funding from the Université Lille 1), as well as several more postdoctoral researchers in 2017 and 2018. Similarly, we hope to be able to continue our Master's Fellowships for another two years, be it at a slightly lower level than in previous years.

The future is uncertain, by nature and quite generally. Specifically, the continuation of the Graduate Program we have set up, and its further strengthening, are essential for us, and are at the time of writing not ensured. CEMPI is an integral part of the new IDEX ULNE proposal, recently submitted and that will be presented to the international jury at the end of February 2017. If successful, IDEX funding will contribute in an essential manner to this effort. The call for proposals of ``International Graduate Schools'' that is announced in the framework of the PIA 3 for the beginning of 2017 is another opportunity that we will be certain to seize in this context.

1.4 Result exploitation

Patents. The tight collaboration between the Labex CEMPI and the Equipex flux has lead to 3 new patents in the period 2015-2016:

-Device and method for selecting eukaryotic cells in a transportation channel by altering the eukaryotic cells by means of electromagnetic radiation WO 2016024061 A1 (accepted)
https://google.com/patents/WO2016024061A1?cl=fr&hl=fr

-Dispositif optique d'excitation pour générer des processus raman stimulés, ensemble de mesure de processus raman stimulés et procédé d'excitation optique pour générer des processus Raman stimulés. Inventeur(s) désigné(s): HAGE Charles-Henri - HELIOT Laurent (submitted March 12016 ; n° 16 51710).

- Fibre amplificatrice légèrement multimode à cœur en piédestal micro-structuré. Submitted to SATT

Knowledge and know-how were shared through various academic and industrial collaborations. The large number of national and international collaborations mentioned in the previous report have been further developed.

The *CEMPI Subseries of Lecture Notes in Mathematics/Physics* is an important element in the publicizing of CEMPI research. The first volume of the series has appeared in 2015: http://www.springer.com/gb/book/9783319190143. The second volume, on "Metrical and dynamical aspects in complex analysis" will appear in the first semester of 2017. It is a by-product of the Painlevé-CEMPI-PhLAM semester on analysis that took place in 2015. A third volume, associated with the 2016 semester on probability and statistics, and which deals with aspects of stochastic geometry, is under preparation and expected to appear in 2018.

1.5 Outreach and visibility. Promotion of CEMPI.

Beyond the actions mentioned in the previous section, the activities we undertook jointly with our privileged international partners also contribute to our visibility and notoriety. For lack of space, we only mention a few examples. There are two on-going joint PhD supervisions with KU Leuven (R. Cluckers (Painlevé) and W. Veys (KUL), supervisors) and one joint thesis with SISSA Trieste that was concluded in 2015 (D. Markushevich (Painlevé) and U. Bruzzo (SISSA), supervisors). Several joint conferences were organised also with KU Leuven, and SISSA Trieste, Max Planck Bonn and Photonics@be. We refer to the CEMPI website for details. The Max-Planck-Institute für Mathematik in Bonn, a CEMPI partner since 2012, became an official co-organiser of the French-German seminar "Automorphic forms and their applications" founded by V. Gritsenko (Lille), J. Brunier (Cologne/Darmstadt), A. Krieg (Aachen) and N.-P. Skoruppa (Siegen) in 2003. In particular, the 47th session of this seminar was held at Max-Planck-Institute in Bonn, on March 1, 2016. These various collaborations with our international partners lead to a considerable number of joint publications as well.

The annual thematic semesters of CEMPI, and the international conferences organized by CEMPI researchers on and off-campus contribute further to its notoriety. As an example of such an on-campus conference, we mention the upcoming French Japanese Zeta-Function conference, which is part of a series of conferences in the framework of the French-Japanese Projects "Zeta Functions of Several Variables and Applications" which are sponsored by the CNRS and the Japanese society for the promotion of science. Additionally, CEMPI has continued to sponsor a number of scientific events taking place outside of the campus, in the organization of which CEMPI members were involved, and devoted to themes at the heart of CEMPI. One such example is the support of CEMPI to the first Congress of the Société Mathématique de France, which took place in Tours in summer 2016. The next edition is programmed in the summer of 2018, and will take place in Lille, at the initiative of CEMPI staff. We also welcomed distinguished visitors, among whom Fields Medalist M. Hairer, in April 2015.

We continue to actively publicize CEMPI, its activities, hiring possibilities and research results. A "publi-reportage'' on CEMPI was published in the magazine " Parlementaires de France" (April 2016) as well as in "Pour la Science" (September 2016). An article will be published in February 2017 on the activities of CEMPI and FLUX in Innovation Review (www.innovationreview.eu)

2. Impact of Labex Label and associated funding obtained

A) Scientific achievement description

CEMPI research is structured in three ``focus areas'', further divided in a total of six ``themes'', a full description of which can be found on the CEMPI website and in its project, referred to above. In this section, we synthetically present the progress made in each of the themes in 2015-2016. It will become

apparent that the core ideas underlying the original CEMPI project have taken on concrete form in the three first years of CEMPI operation. In particular:

- Collaborative research developed between the two partner laboratories, and more generally in novel subjects at the confluence of mathematics and physics has come to fruition in 5 joint publications in 2015-2016.

- Research at the interface between physics, mathematics, physics and life sciences and medicine has established long-term connections outside CEMPI, in particular through a joint PhD supervision with the Labex EGID (European Genomics Institute for Diabetes) successfully completed in 2016. In the framework of the Photonics4Society CPER project, CEMPI teams have built a consortium also including teams from IEMN in Lille (along the 5 top nanotechnology centres in France), bringing together their complementary expertise to develop innovative experimental approaches. This consortium has developed a partnership with the Nanobiophotonics consortium in Ghent, leading to a participation in an ERC consolidator project coordinated in Ghent.

FOCUS AREA 1. THE INTERFACE BETWEEN MATHEMATICS AND PHYSICS

This focus area encompasses three themes. The first is concerned with key problems of a mathematical, physical and technological nature coming from the study of complex behaviour in cold atoms physics and non-linear optics, in particular fiber optics. The two other themes deal with fields of mathematics such as algebraic geometry, modular forms, operator algebras, harmonic analysis and quantum groups that have promising interactions with several branches of theoretical physics.

Focus area 1, Theme 1: Nonlinear dynamics in complex atomic and optical systems

In addition to the highlights presented in Section 1.2, further results obtained in this theme include firstly several collaborative works between mathematicians and physicists that have given rise to a total of 5 publications in peer reviewed journals. These works are concerned with nonlinear complex behavior in cold atoms, quantum entanglement, and optical systems with a special focus on optical fiber systems. Concerning quantum entanglement, we have developed a theoretical framework for the computation of the entanglement of superpositions of two-mode coherent states of light, placed equidistantly on a circle in the phase space. We have also introduced a set of rotationally invariant circular states (RICS) for which an analytic expression of its entanglement can be found. This allows the control of the entanglement in terms of the radius of the circle and the number of components. Second, in a theoretical study, we have shown that large periodic modulations in the coefficients of a nonlinear Schrödinger equation can drastically impact the spatial shape of the Peregrine soliton solutions: they can develop multiple compression points of the same amplitude, rather than only a single one, as in the spatially homogeneous focusing nonlinear Schrödinger equation. Our predictions are in good agreement with numerical findings for an interesting specific case of an experimentally realizable periodically dispersion modulated photonic crystal fiber. Our results therefore pave the way for the experimental control and manipulation of the formation of generalized Peregrine rogue waves in the wide class of physical systems modeled by the nonlinear Schrödinger equation.
Furthermore, in 2015-2016, we obtained a set of results on spatiotemporal dynamics of relativistic electron bunches, in collaboration with Synchrotron SOLEIL. We could record the spatial structures appearing inside electron bunches, thus opening the way to new and extremely direct tests of theoretical models. The measurements required to develop a “terahertz oscilloscope” that is based on the so-called photonic time-stretch strategy.

The PDE specialists of CEMPI have made progress on problems in quantum chaos and in the nonlinear dynamics of various nonlinear PDE’s of mathematical physics such as the (non)linear Schrödinger, Navier-Stokes, Euler and Ginsburg-Landau equations. A representative sample of their results follows. G. Rivière (Painlevé) and CEMPI visitor F. Macia (Madrid) described the long time dynamics of the

Schrödinger equation when the underlying Hamiltonian generates a periodic flow. As a by-product of their analysis, they exhibit the first known examples of such flows for which the classical invariant measures cannot be completely reconstructed from the Wigner distributions of stationary solutions of the Schrödinger equation. G. Rivière (Painlevé) and CEMPI postdoc N. V. Dang studied Gaussian random superpositions of stationary solutions of the Schrödinger equation and analysed the geometric structure of their vanishing locus. More precisely, they consider the lift of these subsets on phase space and show that they equidistribute using methods from Gaussian supersymmetric integration. H. Ueberschar, a CEMPI postdoc, studied two-dimensional Anderson localization in a model with random point scatterers and established the existence of delocalized eigenfunctions in an appropriate regime of sufficiently high energies and low disorder.

Focus area 1, Theme 2: Algebraic geometry, modular forms, with applications to physics.
In 2015-2016, this theme was developed by the members of the Arithmetic and Algebraic Geometry section of the Paul Painlevé laboratory.
G.Bhowmik, J.-Ch. Schlage-Puchta and O. Ramaré have proved Tauberian oscillation theorems for Dirichlet series tending to infinity at some non-real point of the boundary of its domain of convergence.
N. Borne, jointly with A. Vistoli, elaborated the concept of "Nori's fundamental gerbe", a version of Nori's fundamental group scheme without reference point. Jointly with M. Emsalem and J.Stix, he also contributed to anabelian geometry by finding criteria for lifting Galois sections along torsors under algebraic tori.
A. Broustet, jointly with Y. Gongyo, studied the following conjecture: if X is a normal projective variety with a nontrivial polarized endomorphism, then there exists a boundary d such that (X, d) is a log-Calabi-Yau pair. As an evidence for their conjecture, they provide a proof in the cases when X be a Mori dream space or a normal projective surface.
R. Cluckers and F. Loeser have improved their earlier construction of motivic integration, for the mixed characteristic case, in such a way that the new motivic integral specializes to the p-adic integral in all local fields of characteristic (0,p). Jointly with G. Comte, they proved an analog of the Yomdin-Gromov lemma for p-adic definable sets and more broadly in a non-Archimedean definable context. Together with D. Miller, Cluckers proved an important estimate on the decay of Fourier integrals, which implies, in particular, that the Fourier transform of a constructible, Lebesgue-integrable and continuous function is Lebesgue-integrable. Jointly with W. Veys, he generalized conjectures of Igusa and Denef-Sperber about asymptotics of certain exponential sums associated to a multivariate polynomial F.
P. Dèbes has disproved the solvability of the strong Regular Inverse Galois Problem. He showed that there exist finite groups G which do not admit a Q(U)-parametric extension with group G, that is a realization by a field extension F/Q(T) inducing all Galois extensions L/Q(U) with group G via specializations of T to functions f(U) from the field Q(U). He also obtained an effective version of Bertini-Noether and Hilbert Irreducibility Theorems for polynomials in several variables depending on parameters.
M. Dimitrov, jointly with J. Bellaïche, used deformation theory of Galois representations to prove that the p-adic eigencurve is smooth at classical weight-1 points which are regular at p, and also gave a precise criterion for the eigencurve to be étale over the weight space at those points. With D. Ramakrishnan, he established for various arithmetic quotients of the unit ball in C^n the Lang's generalization of Mordell's conjecture.
V. Gritsenko and K. Hulek obtained the first general results about the moduli spaces of polarised Enriques surfaces. They proved that there are only finitely many isomorphism classes of moduli spaces of polarised Enriques surfaces; for the first polarisations of degree smaller or equal to 32, this moduli space has Kodaira dimension equal to minus infinity; if the degree of polarisations goes to infinity,

then for almost all vectors of polarisation the corresponding moduli spaces are equal to the moduli space of Enriques surfaces with 2-level structure. V. Gritsenko, together with C. Poor and D. Yuen, obtained a very effective method of construction of holomorphic Borcherds products using the theta-blocks.
D. Markushevich supervised the co-tutorial PhD thesis "Semistable vector bundles on bubble tree surfaces" by P. Coronica, defended on 22/09/2015 in Trieste, in the framework of a cooperation between CEMPI and SISSA in Trieste, with U. Bruzzo as the thesis co-advisor on the SISSA side. Another instance of the collaboration between Paul Painlevé Laboratory and SISSA was the joint work of Markushevich with Bruzzo and A. Tikhomirov, in which they proved the irreducibility of the moduli space of holomorphic symplectic instantons on the projective 3-space.
P. Popescu-Pampu used Pinkham's method of the explicit smoothing of singularities by sweeping out a cone with its hyperplane sections in order to prove that the total space of the minimal resolution of any non-smoothable simple elliptic surface singularities is diffeomorphic to the Milnor fiber of some non-normal isolated surface singularity with simple elliptic normalization.
N. Raulf determined the asymptotic behavior of moments of class numbers for discriminants in a given arithmetic progression and for fundamental discriminants in the case that the class numbers are ordered by the size of the regulator, and obtained the limit distributions of class numbers in these cases.

Applications of algebraic geometry to theoretical computer science.
D. Grigoriev considers computational complexity problems related to tropical linear systems. He has shown that the problem of solvability of a tropical linear system is equivalent to the problem of coincidence of two tropical linear prevarieties. On the other hand, he has proved NP-completeness of computing the dimension of a tropical linear prevariety. Also he has constructed a partition such that the corresponding tropical Schur polynomial has a polynomial tropical complexity, while the tropical complexity of the corresponding tropical monomial symmetric polynomial is exponential. Note that these two polynomials coincide as tropical (so, piecewise convex linear) functions.

Focus area 1, Theme 3: Operator algebras, operator spaces and quantum groups with applications to physics.
The research advances of CEMPI in 2015-2016 related to this theme range from operator algebras and operator spaces to operator theory, classical and abstract harmonic analysis, as well as dynamical systems and ergodic theory, symplectic and complex geometry, and the theory of differential equations, with various applications to physics. This theme was at the centre of the Painlevé-CEMPI-PhLAM thematic semester 2015. A sample of representative results follows.
Badea and Grivaux have studied Kazhdan sets in topological groups which do not necessarily have Property (T). They studied in particular Kazhdan sets in some amenable groups and obtained a complete characterization of Kazhdan sets in groups such as the Heisenberg groups (answering a question from [B. Bekka, P. de la~Harpe, A. Valette, Kazhdan's property (T), Cambridge Univ. Press, 2008]), the ax+b group, and SL_2(R). They further provided a new criterion for a subset Q of a group G which generates G to be a Kazhdan set. Using this result, they gave an equidistribution criterion for a subset of G which generates G to be a Kazhdan set. An application of their theory to the case where G=Z allows them to answer a longstanding question of Y. Shalom.
S. Malek, with A. Lastra, study the asymptotic behaviour of the solutions related to a family of singularly perturbed linear partial differential equations in the complex domain. The analytic solutions obtained by means of a Borel-Laplace summation procedure are represented by a formal power series in the perturbation parameter. Indeed, the geometry of the problem gives rise to a decomposition of the formal and analytic solutions so that a multi-level Gevrey order phenomenon appears. This result leans on a Malgrange-Sibuya theorem in several Gevrey levels.
A. Sukhov and A. Tumanov extended their previous studies of the Gromov non-squeezing theorem in

infinite dimensional symplectic spaces and applied the results to prove non-squeezing for the nonlinear discrete Schrödinger equation.
S. Ivachkovich and F. Neji studied the sets of convergence for sequences of meromorphic mappings (i.e., the maximal open set on which the sequence converges) and sets of normality for families of meromorphic mappings (i.e., the maximal open set on which the family is normal). Since these sets depend on the type of convergence considered, differerent natural types of convergence are considered.

FOCUS AREA 2. THE INTERFACE OF PHYSICS AND BIOLOGY

The "Physics and Mathematics for Biology" axis aims at developing quantitative and integrative approaches to understand the dynamics of molecular interactions underlying biological functions. We use tools and methods from physics (essentially optics, atomic and molecular physics, and nonlinear dynamics) and mathematics (essentially probability and statistics) to decipher the design principles operating in regulation networks governing cell decisions and cell fate as well as in signaling pathways conveying and processing biological information, and especially mechanisms using dynamical processes. To this aim, we combine imaging techniques in real time in living cells with mathematical modeling of the time evolution of cellular state (gene activity, protein concentration,...). Mathematical modeling is either data-driven to uncover the molecular network at play in a specific biological system and analyze its dynamics, or considers minimal models designed to capture general biological principles. We have developed long-standing collaborations with biologists but also carry out investigations on cells cultured in PhLAM. Mathematical modeling is essential to understand the dynamics of biological regulation networks since mere intuition cannot predict the combined effect of multiple entangled feedback loops, and thus brings truly new approaches to the life sciences. Since the start of the CEMPI project in 2012, substantial effort has been devoted to the study of two biological functions: the circadian clock, which keeps time in living systems and orchestrates many physiological processes, and the response to stress (oxidative, thermal or both), which controls cell fate in adverse conditions. Dysregulation of both functions is associated with severe diseases such as cancer or diabetes. Special attention is given to the stress response of cancerous cells, with a view towards thereby inducing programmed death in those cells. A distinctive feature of our activities is the tight coupling between biological or biophysical experiments and mathematical modeling.

In 2016 the first significant results of a collaboration initiated in 2012 with a leading research center on diabetes and cardio-vascular diseases at Institut Pasteur de Lille (LABEX EGID) have been published in the Cell Reports journal. This collaboration aims at understanding how the mammalian circadian clock and metabolism influence each other, and how disruption of one can perturb the other one. A first mathematical model describing how feeding and fasting cycles entrain the liver clock has been developed and shows excellent agreement with the data. Importantly, it reproduces well the clock disruption observed under nutritional challenges such as a high-fat diet, and predicts that such disruption may be alleviated by administering at precise times of a day a drug compound modulating the activity of clock protein. Preliminary experiments have been planned to check this prediction.

In the stress project, innovative physical, optical and chemical tools have been built to induce oxidative and thermal stresses in living cells with high spatio-temporal resolution, and to allow a precise quantification of the cellular response. This includes tracking the kinetics of reactive oxygen species and of molecular actors related to cellular redox state, as well as gene induction under thermal stress. The current focus is on understanding the high variability of cellular responses to thermal stress (in terms of activities of transcription factors and of triggering of cell death), and potential correlation with phases of the cell division cycle. The goal is to identify precisely lethal doses for thermal stress and how they depend on the cell state. Other studies are carried out in collaboration with the microfluidics team at the IEMN nanotechnology center to characterize the influence of the tumoral environment on adaptation and death of cells subjected to oxidative stress, in particular regarding spatial effects, intercellular communications and modulation of metabolism.

In 2015, a biophotonics team arrived at PhLAM. This team has developed novel approaches to extract more precise and reliable information from Fluorescence Lifetime Imaging Microscopy (FLIM) and Förster Resonance Energy Transfer (FRET) images, used to quantify protein-protein interactions in living cells. This allows one to track in real time the dynamics of molecular assemblies in molecular networks and to identify key mechanisms of regulation. In 2015-2016, the team has contributed its expertise to various collaborative investigations (dynamics of signaling cascades, antibacterial strategies, response of micro-organisms to stress, cell death induction...), in particular to evidence the efficiency of new promising antitumoral compounds in menanoma with a publication in Cancer Cell. It also develops single-particle tracking methods to characterize the fractal trajectories of transcription factors in a crowded and disordered medium with a view to better understand how they regulate transcription. The biophotonics is currently developing experimental approaches to study the coupling of the circadian clock with metabolism in cell cultures with reporters for selected clock genes and key metabolites, as well as the transcriptional aspects of the cellular response to stress, to establish synergies with the other biophysical teams at PhLAM.

On the theoretical side, mathematical models have been used to clarify fundamental aspects of the cellular dynamics. Models have been developed to study the mechanisms of cell differentiation and their theoretical and computational analysis has shed light on sophisticated mechanisms of decision making. In particular, a theoretical study of the coordination of neural progenitor self-renewal and differentation through oscillating dynamics has been published in the well-established biology journal Development. Other investigations have clarified non-intuitive aspects of the cooperative coupling between noise and cellular oscillations as well as of cell-to-cell coupling, which both contribute to the robustness and rapidity of cellular decision making.

An important aspect of our research is long-term collaborations with colleagues developing therapeutic approaches for diabetes and cancer. This strategy is pursued inside a larger consortium associating, besides the CEMPI members, local experts in microfluidics, nanochemistry, acoustics and molecular biophysics from the Institute of Electronics and Nanotechnology of our university, bringing together a wide set of complementary expertises at the interface between physics, mathematics and biology (http://nonlineaire.univ-lille1.fr/AIVBS/). This initiative occurs at an opportune time, since it brings together teams from Lille 1 (Science and Technology) and Lille 2 (Law and Medicine) in a context where the three universities in Lille have decided to merge in the beginning of 2018. As an example of our ability to merge efficiently competences for observing, modelling and manipulating biological systems, several groups from this consortium are involved in an ERC consolidator grant coordinated by Kevin Braeckmans, member of the Nano-Bio Photonics consortium at Ghent University.

FOCUS AREA 3. THE INTERFACE OF MATHEMATICS AND THEORETICAL COMPUTER SCIENCE This focus area explores various problems at the meeting point between theoretical computer science and pure mathematics, in particular algebraic topology and the geometry of graphs and groups.

Focus area 3, Theme 1: Algebraic topology, with applications to theoretical computer science. The research carried out in algebraic topology in the CEMPI project, in 2015-2016, has mostly concerned the mathematical facets of the proposal : the theory of operads, the rational homotopy theory, and the applications of algebraic topology to the study of manifolds. The algebraic topology research group of the project has been strengthened in 2015 by the arrival a new professor (Antoine Touzé) whose research subject is the homology of groups. On the same year, an assistant professor in homotopy theory (David Chataur) has been promoted professor at the Université d'Amiens and has left the team.

A representative list of results, beyond those already highlighted in Section 1.2, follows. A first result, obtained during the period 2015-2016, which we would like to mention in this respect, concerns the cohomology of configuration spaces and has been obtained by Najib Idrissi Kaitouni, a PhD student supervised by Benoit Fresse. Idrissi's work on configuration spaces also provides a solution to a

problem stated in our initial proposal as an objective of the CEMPI project in algebraic topology, namely the computation of the factorization homology in the case of framed manifolds. In short, Idrissi's work generalizes results obtained by Kriz and Totaro on the cohomology of the configuration spaces of projective manifolds, as well as Arnold's computation of the cohomology of the configuration spaces of points in Euclidean spaces. Idrissi precisely considers a generalization of the algebras considered by Arnold in these computations. His main result asserts that these differential graded algebras, which he can associate to any simply connected manifold M by using a Poincaré duality algebra associated to M, are quasi-isomorphic to the cochain algebras of the de Rham forms on the configuration spaces of M. To get this result, he generalizes a construction used by Kontsevich in his proof of the formality of the little disks operads.

The other results obtained in the field of algebraic topology and its applications in 2015-2016 include : a duality theorem that unifies many previous classical duality results, such as the Grothendieck duality in algebraic geometry and the Brown-Comenetz duality in stable homotopy theory (Balmer-Dell'Ambrogio-Sanders) ; a simplicial extension of the Sullivan-Lawrence interval providing an explicit construction of a Quillen model for the rational homotopy theory of spaces (Buijs-Félix-Murillo-Tanré) ; a computation of James's sectional category of the Ganea maps in classical homotopy theory (Doeraene-El Haouari) ; an intrinsic formality theorem for E_n-operads that improve previous formality theorems obtained by Kontsevich and Tamarkin (Fresse-Willwacher) ; a computation of the stability of cup-products that give a new proof of the Steinberg tensor product theorem in group homology (Touzé). Fresse has also supervised the work of a graduate student, Dimitri Gallois, on rewriting theory, the Squier theorem, and the applications of polygraphs in theoretical computer science.

Focus area 3, Theme 2: Graphs and groups, with applications to theoretical computer science. This theme, in its original conception, was mainly concerned with the recent trend in mathematical research, of constructing ``discrete'' versions of existing theories coming from analysis and differential geometry, of applying them to (large scale) studies of graphs and groups, to algorithm design etc. It was decided in 2015 to enlarge it to include a number of classical topics of differential geometry and dynamical systems, often with links also to Theme 1 of Focus Area 1. A representative list of results obtained in 2015-2016, beyond those already highlighted in Section 1.2, follows.

A key theme at the interface of geometric group theory and computer science is that of expander graphs (which represent robust networks, that are difficult to disconnect; equivalently, graphs that have the most distorted embeddings into Hilbert spaces) and of groups with property (T). Within this theme Drutu and Nowak investigate generalizations of Kazhdan's property (T) to the setting of uniformly convex Banach spaces, and consequently introduce a consistent notion of expanders with stronger spectral properties, equivalently expanders with distorted embeddings in larger classes of Banach spaces. The 800 page book "Geometric Group Theory" of C. Drutu and M. Kapovich, will be published in the series Colloquium Publications (the most prestigious series of the American Mathematical Society Publishing House). It contains an exhaustive presentation of key topics of this theme, as well as many new results.

M. Bourdon, B. Kleiner, study quasi-isometry invariants of Gromov hyperbolic spaces, focussing on the l^p-cohomology and closely related invariants such as the conformal dimension, combinatorial modulus, and the Combinatorial Loewner Property. They give a new construction of continuous l^p -cohomology and new examples of hyperbolic groups which do not have the Combinatorial Loewner Property. Another consequence is the existence of hyperbolic groups with Sierpinski carpet boundary which have conformal dimension arbitrarily close to 1, answering questions of Mario Bonk and John Mackay.

V. Gerasimov et L. Potyagailo study different notions of quasiconvexity for a subgroup H of a

relatively hyperbolic group G. Their results imply that relative geometric quasiconvexity is equivalent to dynamical quasiconvexity as was conjectured by D. Osin. They also give a precise characterization In the second part of cocompact action of a subgroups of finitely generated relatively hyperbolic groups in terms of its quasi-convexity properties and its parabolic subgroups.
Juan-Carlos Alvarez Paiva, Florent Balacheff et Kroum Tzanev show that if an optical hypersurface of contact type in the cotangent bundle of the 2-dimensional torus encloses a volume V, then it carries a periodic characteristic whose action is at most $(V/3)^{1/2}$. This result is deduced from an interesting dual version of Minkowski's lattice-point theorem: if the origin is the unique integer point in the interior of a planar convex body, the area of its dual body is at least 3/2.
L. Flaminio, G. Forni and J. Tanis prove bounds for twisted ergodic averages for horocycle flows of hyperbolic surfaces from which they derive effective equidistribution results for horocycle maps. As an application they further improve on a result of Venkatesh on a sparse equidistribution problem for classical horocycle flows proposed by Shah and Margulis and prove bounds on Fourier coefficients of cusp forms which are comparable to the best known bounds of Good in the holomorphic case, and of Bernstein and Reznikov in the Maass (non-holomorphic) case.
Z. Jelonek and M. Tibar, show that the number of bifurcation values at infinity of a polynomial function f : C^2 \to C is at most the number of branches at infinity of a general fiber of f. This upper bound can be diminished by one in certain cases.
For the equation f(x,y)=0, with f irreducible formal power series in two variable without constant term, E. R. Garcia Barroso, P. D. Gonzalez Perez and P. Popescu-Pampu, give two new proofs of an inversion theorem of Abhyankar and Zariski expressing the characteristic exponents of the Newton–Puiseux series corresponding to the solution of the equation for one of the variables, in terms of characteristic exponents of the Newton–Puiseux series corresponding to the solution for the other variable. The result is then generalized to irreducible series with an arbitrary number of variables.
A.B.Tumpach, H.Drira, M. Daoudi, and A. Srivastava describe a novel framework for computing geodesic paths directly on the shape space avoiding complications resulting from the quotient operation. This comprehensive framework is invariant to arbitrary parameterizations of surfaces along paths, a phenomenon termed as gauge invariance.
G.M.Tuynman shows that for any polarization on a symplectic manifold for which there exists a metalinear frame bundle and for any other compatible polarization there exists a unique metalinear frame bundle such that the BKS-pairing is well defined. This implies that a metaplectic frame bundle (nor a positivity condition on the polarization) is not needed to achieve this goal.

THEMATIC SEMESTERS. The Painlevé-CEMPI-PhLAM thematic semesters have become a trademark feature of CEMPI's and play an important role in the realization of the CEMPI project and in the development of its visibility. They take place principally between January and July, but some activities may also extend into the fall. A typical semester is composed of two to four major international conferences, and a number of smaller workshops or meetings, as well as short, intensive post-graduate courses. The activities of the semesters are funded for about 40% by CEMPI, with the rest of the financing coming from other sources: the recurrent funding of the partner laboratories, the ANR projects of the organizers, FEDER funding, etc. In addition, the hiring of CEMPI postdocs and invited scholars is each year coordinated with the theme of that year's semester. The semesters are publicized through the usual channels. About 150 posters are sent to institutions in France and abroad, and publicity is made through our partnership with the Fields Institute. The programs of the semesters can be consulted on the CEMPI website. Note that the 2017 Semester includes a collaboration with a semester at the Newton Institute in Cambridge on related topics.

B) Human resources

The Labex CEMPI enjoys the support of the Université Lille 1, of the CNRS and of INRIA also through their hiring policies.

Three full professors and one assistant professor have been hired at the Laboratoire Paul Painlevé in mathematical fields related to the research of the CEMPI programs in 2015-2016. In 2015, A. Touzé was hired as a full professor in algebraic topology. In the same year, S. Dachian was hired as a full professor in theoretical statistiscs and A. Hardy as an assistant professor in probability theory. In 2016, Nguyên Viêt Anh was hired as a full professor in complex analysis and complex dynamics.

At PhLAM, one assistant professor (A. Rançon) was hired in 2016 and one assistant professor (A. Kudlinski, nonlinear photonics) was promoted to full professor the same year.

In 2015, M. Conforti, a post-doctoral physicist involved in the Painlevé-PhLAM collaboration since 2014, was hired on a permanent researcher position at CNRS (Chargé de recherche). The same year R. Cluckers (Painlevé) was promoted to a senior research position at the CNRS (Directeur de Recherche). Finally, the CNRS hired S. Plus as a research engineer for the photonics group of PhLAM, in 2016.

In January 2016 M. Simon obtained an INRIA permanent research position in the team MEPHYSTO, and as such is member of the Lab. Paul Painlevé. M. Simon is a probabilist working in Statistical Mechanics, who will be instrumental in strengthening the new interactions being within CEMPI, as described in Section 1.

C) Financial resources, leverage effect

Let us first briefly and synthetically recall the CEMPI budget itself. CEMPI has been awarded a total budget of 5M euros for the duration of the contract, which runs for 7 years and 10 months (2012-2019). This amounts to roughly 600 000 euros per year on average, to which 200 000 euros in overhead must be added.

Annual distribution of the budget:
Among the 2 partner laboratories: 400keuros Painlevé, 200keuros PhLAM.
Among the 3 principal budget lines:

Salaries:	65%	390 keuros	(invited scholars ; Postdoc, PhD and master fellowships/internships
Equipment:	20%	120 keuros	
Operating costs:	15%	90 kEuros	

After almost 5 years of operation (since March 2012 officially, but with an effective start in September 2012), CEMPI has committed the following sums:

Salaries:	2 460 keuros (80% of the planned budget)
Equipment:	735 keuros (77% of the planned budget)
Operating costs:	350 keuros (48% of the planned budget)
TOTAL:	3 545 keuros (74% of the planned budget)

One observes an efficient use of the funding, largely respecting the balance between the different budget lines in the original project. The project has run for almost five years out of its almost eight year lifetime, which corresponds to about 63%. Considering that the salary budget includes sums committed for future salaries of PhD students and postdocs with contracts started in the last two years, it is normal that for this budget line already 80% of the budget is committed. As anticipated in the 2015 report, the delay in spending on the salary budget observed in February 2015 has now been completely absorbed.

Some transfers within the internal budget lines of the salary budget will be operated in the coming years. Indeed, we observe an under spending for the ``invited professor'' positions, for which we benefit from other funding through the University, the FEDER and the CNRS. Some of the CEMPI invited professor budget will be used for students and postdocs, respecting the ANR guidelines for such transfers.

It is expected of the ``Laboratoires d'Excellence'' in general and therefore of CEMPI in particular that they show a capacity for attracting additional budgets to complete the funding obtained from the ANR. The following is a list of the main such funds from which CEMPI benefited in 2015-2016.

-FEDER (European funds: 2013-2015) CEMPI: 500keuros
-R. Cluckers (Painlevé) obtained an ERC Consolidator Grant (MOTMELSUM: 2014-2019): 1 Meuros
-V. Gritsenko was appointed senior member of the Institut Universitaire de France (october 2013-october 2018). 75keuros.
-M. Conforti, who joined CEMPI as a postdoc in the photonics team of the PhLAM, in Januari 2014, obtained a three-year fellowship from the ANR for his NoAwe project. 460 K
-About 1.9M euros in 2015 and 2.5M euros in 2016 of additional funding has so far been obtained in tight coordination by the Labex CEMPI and the Equipex FLUX for the period 2015-2016, from a variety of industrial and public sources, among which the ANR, to develop their research and technology transfer projects.
-A further 60keuros in ANR funding was obtained for CEMPI-related research at Painlevé, for contracts that will start in 2017.
-The Université Lille 1 supported CEMPI through its Bonus Qualité Programme, and via PhD funding.

Substantial funding has also been obtained in the context of the CPER project Photonics4Society, already mentioned and further described below.

D) Labex impact on its ecosystem policy

In 2008, the University Lille 1 had been reorganized around thematic sectors such as Environment, Biology and Biotechnologies, Material Science, and disciplinary sectors such as Mathematics and Physics sectors, essentially including the Painlevé and PhLAM laboratories, respectively. The latter were thus relatively isolated. Since the start of the CEMPI project, "Mathematics, Physics and their interactions" has been identified and presented by the University as a research area of excellence, considerably strengthening the two laboratories. Naturally, this theme will also a research priority within the framework of the future Université de Lille that is to be created on January 1 2018 by merging the three universities in Lille (Science and Technology, Law and Health, Human and Social Sciences). Also, the two laboratories will be members of the new Faculty of Science that has been created in preparation of the upcoming merger. In addition, several members of the CEMPI executive committee have actively participated in the elaboration of the IDEX (Initiative d'Excellence) ULNE project (2016-2025) that the three united universities of Lille, together with the CNRS, INRIA and INSERM, have recently deposited in the context of the PIA and that will be evaluated shortly. Similarly, CEMPI has been mobilised to participate in the Convergence Institute REVBIO, an interdisciplinary project of the PIA program, presented in April 2016. The project was very well evaluated (19/20), but not funded at first. A new submission took place very recently (December 2015).

Together with CEMPI, the EQUIPEX FLUX was funded in 2012 to develop optical fibers carrying very high light intensity, harnessing the outstanding optical fiber fabrication facility in Lille. Since then, the two projects have worked in close coordination and strengthen each other mutually. The actions of the period 2012-2014 have been reinforced by the "Photonics4Society" CPER (Contrat de Plan Etat Région), which was approved in the beginning of 2015 and which is now fully operational.

This success, which relied in a crucial manner on the previous successes registered by obtaining the Labex and Equipex quality labels for CEMPI and FLUX, further reinforces the impact of CEMPI on the regional and national ecosystems.

The "Photonics4Society" project puts emphasis not only on optical fiber technology but also on using biophotonics and microscopy for the life sciences and to develop a high-level infrastructure in this area, in close collaboration with research themes of the "Physics and Mathematics for Biology" CEMPI focus area. The latter currently develops a strategy of building long-term partnerships with biologists, medical doctors and pharmacologists and also with colleagues bringing complementary expertises from the physical and engineering sciences. In this context, a long-term collaboration has been initiated two years ago with LABEX EGID (European Genomics Institute for Diabetes), with a joint PhD between Institut Pasteur de Lille and PhLAM. Also the "Photonics4Societey" CPER project teams CEMPI members with colleagues from IEMN, one of the 5 large nanotechnology centers in France, who are experts in microfluidics and nanochemistry. Article in Cell reports mentioned above...

CEMPI has co-financed a study on the impact of mathematics on the GNP of France (EISEM), which was ordered by the network LABEX AMIES. The results of the study were made available publicly in May 2015. The study received considerable press coverage stressing the importance and impact of mathematics on the national economy and as an antidote to unemployment.

3. SOCIO-ECONOMIC IMPACT

3.1 Partnerhips with social and economic actors

We have continued our efforts to increase the economic impact and transfer of knowledge / skills to companies and manufacturers.

-*Workshops* organized since the beginning of CEMPI/FLUX continue to be realized, deliberately focused on industrial concerns. These workshops are conducted by invitation to reduce the dissemination of information to competing manufacturers.

-CEMPI/FLUX have created *two common laboratories with industry*; this constitutes an important step forward in the knowledge transfer and increase of the partnerships with the industrial actors:
Common Laboratory with Prysmian: In recent years, the company Draka - Prysmian Group (world leader in optical cables) has gradually transferred part of its R & D activity in the Nord - Pas de Calais to one of its production plants in Billy Berclau. The industrial and academic partner considered that many of their research activities were complementary and that beneficial synergies would emerge on several specific axes through the merging of the technical know-how and the facilities of both parties. This led to the creation and implementation of a joint laboratory as part of a technical program for the design, modelling, fabrication and characterization of a new generation of optical fibers. The joint research activities focus on the study of loss mechanisms in optical fibers, the impact of OH radicals in hydrogenated atmospheres, slightly multimode or multi-core fibers, inclusions of nanoparticles to modify characteristics of optical amplifiers and the increase of fiber resistance to hydrogen. A dozen people are involved in this joint laboratory in balanced contributions between University / CNRS and Prysmian. This successful collaboration has just been approved for a new 4 year period (2017-2020).
Common laboratory with CEA CESTA: The research laboratory under agreement with CEA DAM Bordeaux (CEA CESTA see: http://www-dam.cea.fr/organisation-competences/cesta.html) has been set up in 2015. It follows many prior works perform in collaboration with CEA: a project under joint partnership in ANR (ANR JCJC FOPAFE) and several contracts to develop power fiber lasers and / or short pulses generators. This work takes place in the framework of the Megajoule laser project. In our collaboration, the objective is to set up more and more all-fiber components, more stable and less bulky than solid solutions currently in place. Recent acquisitions in the context of Equipex FLUX allowed to

progress significantly on high technology deployed in the central FiberTech of the PhLAM laboratory. The CEA CESTA expertise is in the field of power lasers / short pulse lasers. The complementarity between the skills and expertise is remarkable and has already resulted in several patents and numerous publications. In the future, the objective is to develop efficient power laser systems covering a wide spectrum of applications where the market is booming.

-*Creation of a Fiber To The Home (FTTH) platform for teaching*. Fiber To The Home (FTTH) is being deployed in France and the "Hauts de France" region. The operators (Orange, SFR, Numericable…) will deploy their own fiber networks in the large cities of the Hauts de France region. A major training need is currently being identified. We have therefore created an FTTH platform where the teaching is structured into modules: general information on FTTH networks, measurements and controls on FTTH networks, deployment and connection, from the riser to the subscriber. Different types of structures are addressed and deployed: point-to-point (P2P), point-to-multipoint (P2M). A demonstration in EPON (IEE 802.3ah) or in GPON (ITU G.984) is feasible. A part of the model is devoted to the demonstration of the realized FTTH network. Another part is devoted to tests, realizations and training. Finally, this training makes it possible to approach in detail all the parts of an optical network of the optical connection node to the subscriber (distribution network, adduction and internal service).

-*Collaborations with industry* through research actions supported by contracts, ANR , FUI, Europeans are a strong commitment of the Labex Cempi and Equipex Flux as indicated in the list below:
Draka/Prysmian, Nord Pas de Calais : Optical fibers for communications
LSO médical, Nord Pas de Calais, Catheters
Mader, Nord Pas de Calais : Diffusion in optical fibers
Indelec, Nord Pas de Calais : lightning and optics (avec le CERLA)
Genes diffusion, Nord Pas de Calais : Biophotonic
Horiba Jobin Yvon, Nord Pas de Calais : Raman endoscopes and filters
MC2, Nord Pas de Calais : TeraHertz Photonic
***Start up** in preparation, Nord Pas de Calais : Linoptics*
CEA CESTA, Région aquitaine: Specialty fibers and lasers
CEA List/ CEA Tech, Ile de France : Bragg Tower
ONERA, Midi Pyrénées: Brillouin effect and specialty optical fibers
Leukos, Limousin: Fibers for supercontinuum
Novae, Limousin: fiber lasers,
Thales, Ile de France: Systèmes de communication : TiFi
Alcatel, Lucent Ile de France: communication slightly multimodes
Cailabs, Pays de la loire: Mux et Demux
Beam, Alsace lorraine: 3D processing and fibers,
Eolite, Région aquitaine: Specialty optical fibers and lasers
Amplitude systèmes, Région aquitaine: Raman systems;

Finally, the overall sum of additional contracts and projects with industry in the period 2015-2016 reached 1.9M euros in 2015 and 2.5M euros in 2016.

3.2 Relationship with the SATT (Societé d'Accelération de Transfert Technologique)

One of the three new patents mentioned in Section 1.4 is now supported by the SATT in the framework of a maturation program. (CARSIMAGE: Two-beams single fiber-end source for stimulated Raman and nonlinear microscopy, see : http://sattnord.fr/recherche-doffres-de-technologies/carsimage-two-beams-single-fiber-end-source-for-stimulated-raman-and-nonlinear-microscopy/721/?l=en)

Discussions for maturation are under way for two other patents.

3.3 Commercial relations with European public-private partnership research institutes, within the Framework Programmes

The development of commercial relations is not one of the central objectives of the LABEX CEMPI. Nevertheless, recent results on mutualisation of optical amplifiers have been entered in the patenting process and a start-up is expected to emerge from this. A business plan for this start-up has already established.

3.4 Promotion measures for knowledge dissemination ; schedule, durability of the measures (excluding publications in scientific journals)

CEMPI negociated with Springer the creation of a CEMPI Subseries of LNM/LNP. The contract was signed in 2014. The first volume has appeared in 2015. The second is being finalized and the third is being written. For details see Section 1.4 above.

APPENDIX

Midterm Report on the Labex CEMPI

ANR June 2015

1. Noteworthy productions

1.1. Outstanding progress regarding research

The mathematicians in this LABEX discovered a means to translate abstract harmonic analysis to the derivation of quantum error correcting mechanisms. It is noteworthy that this work included theoretical mathematics published in a main-line physics journal. This is an example of how this LABEX is working to develop serious research connections between an existing mathematics lab and as existing physics lab.

Other very relevant research has been developing new stable waveforms for model optical channels. This should be directly relevant to French communications industry.

1.2 Striking progress in other “Labex” fields

a. Formation

There were four existing masters programs to which this LABEX is now actively recruiting students. They are working to make quick admissions and funding decisions, and taking advantage of their foreign faculty in accurately evaluation the applications of foreign students.

b. Valorization

The relations with partners in medical and communications industry have put this LABEX in a position to start enhancing the local economy. There are good opportunities now for mathematicians to provide the tools for speedier design of multi-structured optical fibres; multi-structured fibres being required to satisfy the demand for higher data throughput.

c. International (outreach, attraction, networking…)

The LABEX CEMPI has been recruiting, with some success, postdoctoral fellow and short-term visiting researchers from other countries. The researchers involved in CEMPI are frequently publishing with coauthors in a variety of countries.

2. Added-value resulting from labelling and funding as a “Laboratoire d’Excellence”

This LABEX has already gathered significant funding from other sources, including industry. Moreover, local hiring into permanent positions seems to be coordinated with the goals of the LABEX.

3. Main weaknesses

3.1. Main weaknesses that might require corrective actions regarding the research performed in the “Labex”

No apparent weakness in this area.

3.2 Main weaknesses that might require corrective actions regarding other fields of the “Labex”

a. Formation

No apparent weakness in this area.

b. Valorization

No apparent weakness in this area.

c. International (outreach, attraction, networking…)

It is not clear that sufficient international contacts have been made to allow for a good flow of international professors to visit. The partnership with the Fields institute will be important in this regard, and individual researchers may need to travel more to conferences to make the personal research connections needed to increase the pool of interested visitors.

4. “Labex” contribution to structuring the gathered scientific strengths (governance, synergy, common scientific programming, visibility…)

There seems to have been a solid effort at coordinating research efforts.

5. Beyond scientific results specifically obtained by the “Labex”, give an assessment on its contribution to the development, outreach and overall visibility of the concerned institutions and of the corresponding site.

The funding obtained from industry is a clear sign of improved visibility.

6. Overall opinion and recommendations

Overall, LABEX CEMPI is doing a good job in two essential areas. The first area is in making a coordinated effort to get more mathematicians active in interdisciplinary research relevant to local industry and academic laboratories. The second area is in boosting the number of graduate students in their masters program. They are also retaining more masters students to stay for the PhD program. There efforts to engage industry are expected to have a substantive impact on the local economy and help their graduates find mathematically relevant employment.

The LABEX CEMPI is playing an important role in the IDEX Lille bid to unify the universities in the Lille region. We were very impressed that this was the only presentation to include a SWOT analysis.