Heidmann Pierre | Postdoctorant

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Sujet de Recherche

La structure quantique des trous noirs

Education

École Normale Supérieure Ulm **Paris**
Master 2 *2014–2015*
Master de Physique Théorique mention bien.

École Normale Supérieure de Lyon **Lyon**
Master 1 *2013–2014*
Master de Physique mention très bien.

Lycée Louis le Grand & École Normale Supérieure de Lyon **Paris-Lyon**
Licence et classe préparatoire *2010–2013*
Classe préparatoire Maths-Physique et Licence de Physique mention très bien.

Expériences

Johns Hopkins University **Baltimore US**
Postdoctorat *Oct 2019 –*
Superviseur: Ibrahima Bah

IPhT **Saclay**
Thèse *Sept 2016 – Aout 2019*
Titre: *Les micro-états de trous noirs en Théorie des Cordes : noire est la couleur, régulières sont les géométries ?*
Superviseur: Iosif Bena

APC **Paris**
Stage *Dec – Avr 2015*
Titre: *Les trous noirs en théorie quantique à boucles*
Superviseur: Karim Noui

LPT **Orsay**
Stage Master *Jan – Fev 2014*
Titre: *Le spectre des bosons de jauge dans le modèle Randall-Sundrum*
Superviseur: Gregory Moreau

LPA **Paris**
Stage Master *Avr – Jul 2013*
Titre: *Developpement de qubits supraconducteurs*
Superviseur: Benjamin Huard

Institut Langevin **Paris**
Stage License *Avr – Jul 2013*
Titre: *Optique dans les milieux diffusants*
Superviseur: Sylvain Gigan

Enseignement :

2012 – 2019

— 192 heures d'enseignements à l'université pendant le doctorat (classe de ∼30 élèves) : Travaux dirigés d'électromagnetisme (L2) de mécanique (L2), introduction à mathematica (L3) et préparation aux concours (L2).
— 100 heures de cours particuliers de mathématiques à des étudiants en classe préparatoire.

Production scientifique

Publications

2014: O. Katz, P. Heidman, M. Fink, S. Gigan, *Non-invasive single-shot imaging through scattering layers and around corners via speckle correlations*, **Nature Photonics**

Voir à travers la peau avec un appareil photo **Le Monde**

2016: P. Heidmann, H. Liu, K. Noui, *Semi-classical analysis of black holes in Loop Quantum Gravity : Modelling Hawking radiation with volume fluctuations*, **Phys. Rev. D**

2017: P. Heidmann, *Four-center bubbled BPS solutions with a Gibbons-Hawking base*, **JHEP**

2017: I. Bena, P. Heidmann, P. Ramrez, *A systematic construction of microstate geometries with low angular momentum*, **JHEP**

2018: I. Bena, P. Heidmann, D. Turton, *AdS_2 Holography : Mind the Cap*, **JHEP**

2018: P. Heidmann, S. Mondal, *The full space of BPS multicenter states with pure D-brane charges*, **JHEP**

2018: P. Heidmann, *Bubbling the NHEK*, **JHEP**

2019: P. Heidmann, N. P. Warner, *Superstratum Symbiosis*, **JHEP**

2019: I. Bena, P. Heidmann, R. Monten, N. P. Warner, *Thermal Decay without Information Loss in Horizonless Microstate Geometries*, **SciPost Phys**

2019: P. Heidmann, D.R. Mayerson, R. Walker, N. P. Warner, *Holomorphic Waves of Black Hole Microstructure*, submitted to **JHEP**

Présentations orales et posters

2018: Présentation à Strings, Cosmology, and Gravity Student Conference, *Construction of microstate geometries with low angular momentum*

2018: Présentation au Seminaire de l'IPhT, *Horizon-scale microstructure via the microstate geometry programme*

2018: Présentation au Colloque de l'IPhT 2018, *Black holes in String Theory*

2018: Poster au 10th anniversary of ERC

2019: Présentation à Johns Hopkins University, *Microstate Geometries and the Microstructure of Black Holes*

Langues

Français (maternelle), Anglais (courant), Allemand (débutant)

Prix et bourses

2010: Troisième prix aux Olympiades nationales de Physique

2012: Admis à l'ENS de Lyon (classé $21^{ème}$)

2016 –2019: Bourse de thèse de l'ENS Lyon

2019 –2022: Bourse de Postdoctorat de Johns Hopkins University

PROCES VERBAL DE SOUTENANCE DE DOCTORAT

à déposer dans les 3 jours ouvrés après la soutenance au service de scolarité de l'établissement de préparation du doctorat daté et signé

Monsieur Pierre HEIDMANN
ECOLE DOCTORALE : Physique en Île de France
ETABLISSEMENT DE PREPARATION DU DOCTORAT: Université Paris-Sud

Titre de la thèse : Les micro-états de trous noirs en Théorie des Cordes: noire est la couleur, régulières sont les géométries?
Spécialité de doctorat : physique
Date de soutenance : 27 juin 2019 Heure : 14h30 Lieu : Amphithéatre Bloch Amphithéatre Bloch Bat 774 CEA, Orme des Merisiers, 91191 Gif-sur-Yvette

Décision du Jury

☑ Admission

☐ Ajournement

Avis du Jury sur la reproduction de la thèse

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Des modifications mineures seront toujours nécessaires au moins pour mentionner sur la page de couverture le nom du président du jury en vue du 2nd dépôt légal de la thèse.

☐ Corrections majeures demandées par le jury
Si des corrections majeures sont demandées, identification du **membre du Jury désigné par le président** pour vérifier les corrections :
Nom, prénom, titre et fonction dans le jury :

____

Dans ce cas, le président du jury complète, date et signe le formulaire de vérification des corrections majeures apportées à la thèse et le remet au membre du jury chargé de la vérification.

Civilité, Nom et Prénom	**Titre**	**Fonction dans le Jury**	**Signature**
M. Iosif BENA	I-CEA	Directeur de thèse	selon l'arrêté du 25 Mai 2016, le directeur de thèse participe au Jury mais ne prend pas part à la décision
M. Boris PIOLINE	Directeur de Recherche	Examinateur ☑ Président	[signature]
Mme Andrea PUHM	Chargé de Recherche	Examinateur	[signature]
M. Stefano GIUSTO	Associate Professor	Examinateur	[signature]
M. Rodolfo RUSSO	Professeur	Examinateur ☐ Président	[signature]
M. Bert VERCNOCKE	Associate Professor	Rapporteur	[signature]

RAPPORT DE SOUTENANCE DE DOCTORAT

à déposer si possible trois jours ouvrés après la soutenance et au plus tard un mois après la soutenance au service de scolarité de l'établissement de préparation de la thèse, daté et signé

Monsieur Pierre HEIDMANN
ECOLE DOCTORALE : Physique en Île de France
ETABLISSEMENT DE PREPARATION DU DOCTORAT: Université Paris-Sud

M. Pierre Heidmann a présenté ses travaux de thèse sur les micro-états de trous noirs en théorie des cordes. Ces travaux représentent des avancées importantes sur une question centrale de la gravité quantique, étroitement liée au paradoxe de l'information, qui est d'identifier l'origine microscopique de l'entropie de Bekenstein-Hawking. Ils visent à développer l'hypothèse qu'une large classe de ces micro-états peut être décrite par des solutions de la supergravité, régulières et sans horizon, qui ne diffèrent des solutions de trous noirs qu'au voisinage du rayon de Schwarzschild. M. Heidmann a développé et généralisé les techniques de construction de ces solutions dans une variété de contextes, incluant les trous noirs supersymétriques, quasi-extrémes et les trous noirs en rotation, en a étudié les propriétés de diffusion et d'émission thermique et a proposé une nouvelle approche pour l'holographie pour les espaces anti-de Sitter en dimension 1+1. Ces travaux impressionnants ont fait l'objet de 5 publications et 2 preprints avec une variété de collaborateurs, dont deux en auteur seul. Le mémoire de thèse fournit une introduction détaillée et très pédagogique qui fournira un excellent point de départ pour les recherches ultérieures dans ce domaine. Durant la présentation, M. Heidmann a résumé ses travaux de manière claire et pédagogique, et les a mis en perspective dans le cadre de la recherche en gravité quantique et théorie des cordes. Ses réponses ont démontré sa grande maîtrise de ce sujet hautement technique.

Au vu de l'importance des résultats obtenus et de la qualité de la soutenance et du mémoire, le jury à l'unanimité décide de décerner à M. Heidmann le titre de docteur de l'université Paris Sud et de lui accorder ses félicitations.

Civilité, Nom et Prénom	Titre	Fonction dans le Jury	Signature
M. Iosif BENA	I-CEA	Directeur de thèse	
M. Boris PIOLINE	Directeur de Recherche	Examinateur ☑ Président	
Mme Andrea PUHM	Chargé de Recherche	Examinateur	
M. Stefano GIUSTO	Associate Professor	Examinateur	
M. Rodolfo RUSSO	Professeur	Examinateur ☐ Président	
M. Bert VERCNOCKE	Associate Professor	Rapporteur	

Bert Vercnocke,
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Concerns: assesment of PhD thesis by Pierre Heidmann

Dear PhD school-representatives,

I have read the doctoral thesis of Pierre Heidmann and report on it below. I start with an overview of the various parts and end with an overall (positive) assessment; I hold a **favorable opinion** on the quality of the manuscript. Pierre Heidmann is a young researcher whose papers I have followed closely, as the research of the thesis touches upon my own research over the last few years.

The first thing that stands out when reading the thesis, is its bredth and depth. In the thesis, a wide range of topics is presented, within black hole research in string theory. The scope is very broad for someone at this level. It falls under the bigger category of fuzzball research and in particular the microstate geometry programme. This is a broad field; the thesis covers well nigh all of its subdomains, ranging from well-known multi-center solutions to state-of-the art calculations with new solutions known as superstrata.

The second thing is the quality of the work: all papers presented are cutting-edge, with important conceptual and technical advances

After a good main introduction, placing ideas of black hole physics and their microstates into the context of gravitational and string theory research, the thesis continues with three main parts that combine the research of the PhD candidate in a very logical and orderly fashion. I discuss all three parts consecutively.

Part I: discusses a review of microstate geometry basics. This covers supersymmetric solutions and techniques to obtain them. Apart from the supersymmetric solutions that have been discussed in the last 15-20 years, also supersymmetry-breaking solutions and constructions are briefly discussed. This is a very good, broad and necessary part to put the research into context and I believe such anaintroduction can only be written with a clear mastery over the broad subject.

Part II: goes into Heidmann's research on the construction of different kinds of microstate geometries: multi-center solutions, superstrata and applications to rotating black holes.

In Chapter 4, he gives a very clear overview of the two important works (first two on own paper list) which give an explicit proof that also multi-center solutions can have low values of angular momentum; a previous handicap of such solutions that has now been overcome. Chapter 4 in particular combines those two references in a very insightful manner, that adds to the published versions of those papers.

In chapter 5, Heidmann reviews his work on counting multi-center solutions. By topic a new an independent direction, showing once again a mature and diverse interest. The derivation of the results are sound. I have one minor comment with this chapter. I feel that a connection to the Crnkovic-Witten phase space quantization would have been insightful. That quantization is normally used to count the number of classical bound states, see for instance the counting used for supergravity multi-center states in hep-th/0807.4556 or earlier work of Rychkov in the 2-charge system. What about the connection to the quiver states here?

Chapter 6 gives a technical account of Heidmann's construction of a generic single-mode superstratum, an extension of known solutions. Regarding the construction of superstrata wth an arbitrary number of excitation, there is (p. 110:) "no further obstruction" to constructing them. The technical prowess here once again is shining through. There seems to be no hint on the relation to CFT states; that would be interesting to see at some point.

Chapter 7 treats an impressive piece of solo work. In this chapter, Heidmann takes a big step towards microstate geometries for rotating black holes -- a holy grail of the microstate geometry programme. A basis for such a construction was laid in ref. [127], but no one so far succeeded in building a wide family of warped-AdS3 solutions relevant for the extremal Kerr geometry. This construction has been attempted in the past by others, but no one got as far as Heidmann did, and he did so on his own. The work is based on almost-BPS solutions, detailed spectral-flow transformations, and carefully solving a set of conditions on the parameters of the solution. This marks a new application of technology away from supersymmetry. At this moment, the microstate geometries constructed here are ahead of the understanding of the CFT states and could in fact enlighten the understanding of the mysterious field theory holographically dual to the Near-Horizon Extremal Kerr geometry. At the end of the last section 7.4., Heidmann makes a remark about multipole structures; it might well be that those turn out to hold very little information on the CFT state. Ths raises a question, whether that structure is close to the photon sphere (wich determines the ringdown in a gravitational wave experiment), or rather the horizon (whichis not immediately probed in the prompt ringdown). For near-extremal Kerr solutions, those two surfaces get ever closer; it woul be interesting to disentangle the structure in term;s of those surfaces.

Part III: explores features of microstate geometries such as those discussed in the other parts of the thesis. Bothchapters use various properties of wave equations and their solutions in multi-center and superstratum backgrounds.

Chapter 8 presents interesting remarks on AdS_2/CFT_1 holography, a long-standing research question, and gives a concrete handle on this problem from multi-center and superstratum solutions with AdS_3 asymptotics. There is also a whole set of new questions that are uncovered, and partially answered, showing great intuition beyond the calculations. I have some questions about the interpretation of this chapter (the motivation for the working hypothesis that UV physics of AdS_2 is not altered), that I plan ask during the defense.

Chapter 9 gives a lot of detail on how to calculate a response function for scalar fields in superstrata. This chapter, which is based on an excellent paper (both in the way its written and in the results it holds), presents two important landmarks: First, the result of boundary-to-boundary Green function, in momentum and position space, and how that clearly shows how superstrata can look thermal for a long while, but still reveal their microstructure; and other observations based on this calculation. Second, to achieve this, Heidmann and collaborators had to develop a new technique, which is obtained in a very physically motivated way. Recently I have been working on a very similar project, and encountered the same issue; I can tell from first hand that those 2 achievements were highly non-trivial. I like that this chapter tries to be pedagogical alongside the technicalities, and has a wide set of conclusions--some of the earlier chapters (e.g. ch. 7) end in a rather short conclusion. There are some physical questions left unanswered, such as the relation to flat-space physics and gravitational wave observations, that naturally come to mind. Although this is beyond the scope of this work, I would like to discuss those with Heidmann during his defense.

Based on reading, I prepared a number of additional questions that I will discuss during the defense but will not further detail here.

Taken together, the thesis is a very well-organized and clear representation of Heidmann's excellent and at times ground-breaking research. The thesis is not a mere collection of papers, but is well introduced and molded into a highly readable and self-contained form. I would even advice this to beginning PhD students as a standard work to learn about fuzzballs and especially the latest developments regarding the microstate geometry programme.
The research presented in this thesis shows a mature researcher at work, who has written very good papers, two of them as single author, and being a key contributor in other projects. Those papers made substantial contributions to the field of research: from completely new multi-center solutions with hitherto unknown properties; the first microstates for near-extremal Kerr; the first good technical hint about the geometry of AdS_2 microstates; and a decelopment of a new technique and application to the study of superstrata. The last two chapters in particular show how the new constructions of Heidmann and collaborators hold a lot of new and important physics and mean big breakthroughs in the field of black holes physics in string theory.
The technical and conceptual understanding displayed in this thesis surpasses the standard expected of a graduating PhD student. As this is based on only 2,5 years of full research (not counting the first semester of Heidmann's doctoral period, which was taken up by a PhD school), the research output and quality of the manuscript are all the more impressive.

In light of the above assessment, I have a **highly favorable opinion** of the thesis of Pierre Heidmann, and find that this thesis definitely passes the expected requirements.
Sincerely yours,

Bert Vercnocke,
Assistant Professor at KU Leuven

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École Doctorale
Physique en Île de France
ED 564

Lyon, 6 June 2019

Report on the PhD thesis of Pierre HEIDMANN

The thesis of M. Pierre Heidmann entitled "*Black-Hole Microstates in String Theory: Black is the Color but Smooth are the Geometries?*" reports on his work on black-hole physics, more precisely on constructing supergravity solutions within the fuzzball proposal and the microstate geometry program. It is based on a collection of 7 original articles put together with a general introduction to the field, the complex of problems addressed and the techniques used and developed.

Part I of the thesis, together with the introduction, offers a very readable introduction to the basic concepts of black holes and black hole thermodynamics in general relativity and string theory. It introduces the fundamental supergravity theories in ten and eleven dimensions which set the stage for the subsequent investigations, as well as the web of dualities relating these theories. The five and six-dimensional theories relevant for the work are derived by dimensional reduction. Finally, supersymmetric solutions in these theories are presented with a general discussion of the respective BPS equations of motion followed by a detailed discussion of their specific solutions. Notably, these include the three-charge supersymmetric black holes and smooth multicenter bubbling solutions in 5D and the supertube and superstrata solutions in 6D, respectively.

Part II comprises 5 original articles devoted to the construction of new classes of smooth horizonless microstate geometries, central to the fuzzball proposal. Its first chapter, based on publications arXiv:1703.10095 and arXiv:1709.02812, presents systematic methods for the construction of scaling regular multicenter solutions. Remarkably, with a well-defined parameter space it is shown that certain multicenter smooth solutions in six dimensions can have arbitrarily low angular momentum.
The remaining chapters of this second part embed the original articles arXiv:1810.10019, arXiv:1903.07631, and arxiv:1811.08256, respectively. They present an analysis of the space of BPS states in type IIA string theory on T^6 wrapped by particular D6-D2 branes, the construction of multi-mode Superstrata in six dimensions, as well as the construction of a family of smooth bubbling microstate geometries asymptotic to the near-horizon region of extremal five-dimensional Kerr black holes. Especially, the two latter constructions provide important tools with immediate applications for holographic dualities.

Finally, Part III of the thesis presents two articles devoted to some fundamental questions and applications. Its first chapter is based on arXiv:1806.02834 and presents classes of asymptotically AdS_2 supergravity solutions. The analysis of linearized excitations around these backgrounds points to new insights into AdS_2/CFT_1 holography. The second chapter of this part is based on the very recent arXiv:1905.05194 and develops technology for the computation of certain boundary-to-boundary scalar Green functions and holographic correlators, relevant for the analysis of the scattering process in microstate geometries.

Several technical appendices complete the presentation.

In summary, this thesis presents an impressive collection of new results, situated within a particularly broad spectrum, ranging from the construction of new classes of smooth horizonless microstate geometries to black hole applications in holography and scattering processes. It introduces and develops new technology that may prove very useful for further investigations, and puts these to concrete use in order to address conceptually challenging questions, in particular within the context of AdS_2 holography. The work is situated within a very active and quickly developing field of research in modern black hole physics. It has given rise to four publication in the international refereed Journal of High Energy Physics together with 3 recent preprints. Notably, these include two single author publications by the candidate.

The thesis is certainly acceptable for presentation and defense for which I pronounce an ‘avis favorable’.

Henning Samtleben
Professor of Physics,
École Normale Supérieure de Lyon