

Holography and Magnetic Catalysis of Chiral Symmetry Breaking

Final Report

Veselin Filev

1 Summary

The meeting took place in Dublin, Ireland during November 19-21. The workshop brought together researchers from the fields of String Theory and Phenomenology working on applications of the AdS/CFT correspondence relevant to the effect of Magnetic Catalysis of Chiral Symmetry Breaking. Our goal was to gather representatives of the leading research groups working in this area and obtain an integrated view of the literature written on the subject.

There were twenty two participants and twelve speakers. The majority of the talks reported holographic studies of high energy physics systems subjected to the influence of magnetic field. The numerous examples of configurations exhibiting Magnetic Catalysis of Chiral Symmetry Breaking confirm the universal nature of this effect and the relevance of the holographic approach to such studies.

Another part of the talks reported holographic studies of condensed matter systems subjected to external magnetic field. An example of Magnetic Catalysis in Graphene has been presented, as well as studies of Quantum Hall Effect. This aspect of the meeting was an example of a fruitful exchange of ideas between the condensed matter and high energy physics communities.

I believe that the stimulating environment of the meeting will affect positively the future development of the field.

2 Scientific Content

I will describe the talks in their chronological order:

The first talk was given by Prof. Brian Dolan from NUI Maynooth. The title of the talk was: "Electromagnetic duality in AdS/QHE: magnetic monopoles and the quantum Hall effect".

In his talk Brian Dolan gave an overview of the quantum hall effect and the holographic approach to its description. He first reviewed the basics of the quantum hall effect and the

theoretical description of the fractional quantum hall effect. The second part of the talk focused on the holographic description of the quantum hall effect. The speaker first reviewed the relevant AdS/CFT dictionary and the literature dedicated to the subject starting from the pioneering work of Hartnoll and Kovtun, where they analyze a class of strongly interacting 2+1 dimensional conformal field theories in a transverse magnetic field using a holographic description of a dyonic black hole in AdS4. The talk was very well accepted by the participants. It provided an important condensed matter background, relevant for the condensed matter applications of the holographic duality.

The second talk was given by Dr. Kim Keun-Young from University of Amsterdam. The title of the talk was: "mu-T-E phase diagram of the D3/D7(D5) holographic dual at finite B".

In his talk Dr. Keun-Young covered his recent studies of the phase structure of holographic gauge theories dual to the D3/D5 and D3/D7 brane intersections in the presence of various control parameters such as temperature, chemical potential and electric and magnetic fields. In the D3/D7 with massless quarks, at zero chemical potential, the theory displays a first order thermal transition where chiral symmetry is restored and simultaneously the mesons of the theory melt. At zero temperature, these transitions with chemical potential are second order and occur at different chemical potential values. At finite quark mass the second order transition for chiral symmetry becomes a cross over and there is a critical point at the end of the first order transition, while the meson melting transition remains similar to the massless quark case. In the D3/D5 system they explore the full temperature and chemical potential dependence of the 2+1 dimensional theory in the presence of a magnetic field. The theory displays separate transitions associated with chiral symmetry breaking and melting of the bound states. The final part of the talk was dedicated to chiral symmetry restoration with increasing temperature and density in gauge theories subject to mutually perpendicular electric and magnetic fields using holography. Dr. Keun-Young reported about the chiral symmetry breaking phase structure of the D3/D7 and D3/D5 systems in the temperature-density-electric field directions.

The third talk was given by Professor Nicholas Evans from University of Southampton. The title of the talk was "Novel Phase Transitions In 3d & 4d".

The talk of Professor Evans was a continuation of the topic initiated by Dr. Kim Keun-Young. Professor Evans began with a brief introduction to the relevant AdS/CFT dictionary and moved to the holographic description of Chiral Symmetry Breaking in flavour brane set ups. Next Professor Evans focused on the particular case of chiral symmetry breaking in external magnetic field in the D3/D7 set up. He presented evidence for the effect of Magnetic Catalysis of Chiral Symmetry Breaking and then moved to study the chiral restoration transition at finite temperature.

The next part of the talk was dedicated to the study of the D3/D5 and D3/D7 systems in both magnetic field and chemical potential and in particular the rich phase structure of

these theories. He clarified the lessons that one can learn for QCD from these holographic gauge theories. In the 1+2 dimensional D3/D5 field theory he presented an example of BKT transition.

The final part of his talk was dedicated to the role of a holographic Wilsonian cut-off in simple probe brane models with chiral symmetry breaking/restoration phase transitions.

The fourth talk was given by Tigran Kalaydzhyan from University of Hamburg. The title of the talk was "Magnetic catalysis in an expanding quark-gluon plasma and on the lattice".

In his talk Tigran Kalaydzhyan focused on the holographic studies of Magnetic Catalysis in expanding plasmas. This topic is particularly relevant since the plasma produced in heavy ion collision is expanding. The holographic approach employed by Kalaydzhyan and his collaborators is to consider flavour brane embeddings in a time dependent gravitational background. They study the dependence of the critical time on the magnetic field and find that the stronger the magnetic field the earlier the phase transition takes place.

In the second part of his talk Kalaydzhyan reported about progress on the study of the effect of Magnetic Catalysis on the lattice.

The fifth talk was given by Professor Gordon Semenoff from University of British Columbia. The title of the talk was "Magnetic Catalysis in Graphene".

The talk of Professor Semenoff was dedicated to the studies of Graphene both holographic and with conventional field theory methods. He began his talk by providing a brief introduction to the physics of Graphene its discovery and its theoretical description. He emphasized that many high energy physics phenomena have analogues in Graphene. He gave an example of a magnetic catalysis of chiral symmetry breaking in Graphene.

The second part of his talk was dedicated to the holographic description of Graphene. He introduced the holographic set up and clarified the main differences between the holographic system and real life Graphene and what can the AdS/CFT correspondence teach us about Graphene. In particular he reported his result on diamagnetic and conductive properties of Graphene.

The talk of Professor Semenoff was very well accepted by the audience. It was a privilege to listen to one of the pioneers of this field.

The sixth talk was given by Dr. Stefano Bolognesi from The Hebrew University of Jerusalem. The title of the talk was "Holographic Magnetic Catalysis from bottom-up".

In his talk Dr. Bolognesi reported about his research on the holographic description of Magnetic Catalysis from a bottom-up approach. He began by a brief introduction to the effect of Magnetic Catalysis of Chiral symmetry breaking in conventional field theory. He focused on the 1+2 dimensional case as the simplest example of this effect. Next he moved to the bottom up approach to magnetic catalysis. He studied fermions in four dimensional Anti de'Sitter space. The dual field theory lives in 1+2 dimensions. He spend

a lot of time on the definition of the relevant AdS/CFT dictionary. He also reviewed the basic properties of fermions in Anti de Sitter space. The most important result that he reported is the identification of the operator which condenses in magnetic field and realizes Magnetic Catalysis of Chiral Symmetry Breaking. A novel feature of this approach is that the condensing fields would correspond to composite object in the dual field theory more technically the dual operator is a double trace operator.

His talk provided an important example of Magnetic Catalysis in a bottom-up approach.

The seventh talk was given by Professor Andreas Schmitt from Vienna University of Technology. The title of the talk was "Inverse Magnetic Catalysis" .

In his talk Professor Schmitt reported his work on the effect of Inverse Magnetic Catalysis that he and his collaborator observed in D4/D8 set up also called holographic QCD. He began his talk by reviewing the basics of the D4/D8 set up and his relevance to real life QCD. He also reviewed the work of other people on the properties of this model in external magnetic field and at finite temperature when a conventional magnetic catalysis is observed. Next he introduced chemical potential and showed how the phase structure of the model is changed to allow for a phase where magnetic field favours the chiral symmetric phase. He names this phenomena "Inverse Magnetic Catalysis". He ended his talk discussing possible applications of his studies.

His talk provided an important example of Inverse Magnetic Catalysis, a phenomenon which is now observed in lattice QCD.

The eighth talk was given by Dr. Niko Jokela from University of Santiago de Compostela. The title of the talk was "Towards magnetic catalysis in flavored ABJM".

In his talk Dr. Jokela focused on the recent study of the flavoured ABJM model which is dual to an exotic 1+2 dimensional field theory. He began his talk by providing a brief review of the ABJM model and the addition of flavour branes to this set up. He then focused on the back reaction of the flavour branes and the finite temperature analogue of the background. He also reported on his study of the model in various control parameters such as chemical potential and electric and magnetic fields. He reported a regime where a Magnetic Catalysis of Chiral Symmetry breaking is realized.

His talk gave an example of the universality of the effect of Magnetic Catalysis.

The ninth talk was given by Dr. Matthew Lippert from University of Amsterdam. The title of the talk was "Brane models of 2+1-dimensional fermions".

In his talk Dr. Lippert discussed the properties of brane models describing fermions in 1+2 dimensions. He began with a brief introduction to the holographic approach to fermi liquids. The holographic set up is a cousin of the D4/D8 set up namely D3/D7 and D3/D5 brane systems holographically dual to 1+2 dimensional fermions at strong coupling. These systems have applications in holographic studies of the Fractional Quantum Hall Effect and in Graphene. He proceeded by describing the computation of the Hall conductivity, zero

sound mode and other transport properties. His talk was an example of the wide range of physical systems captured by the properties of the D-branes.

The tenth talk was given by Dr. Dimitrios Zoakos from University of Porto. The title of the talk was "Unquenching the Holographic Magnetic Catalysis" .

In his talk Dr. Zoakos reported on a recent study of the holographic effect of Magnetic Catalysis beyond the quenched approximation, which corresponds to taking into account the backreaction of probe flavour branes. He began his talk by describing the technique used to introduce backreacted flavours. He then reviewed the holographic approach to Magnetic Catalysis in the D3/D7 system and described how this set up can be used to produce a supergravity background which captures the effects of fundamental loops on the flavour dynamics. In the last part of his talk he reported the results of his collaboration on the correction to the quark condensate due to fundamental loops. The results suggest that magnetic catalysis is enhanced.

His talk was important as this is the only holographic study of magnetic catalysis beyond the probe approximation.

The ninth talk was given by Dr. Matthias Ihl from Dublin Institute for Advanced Studies. The title of the talk was "Magnetic Catalysis in the Backreacted Kuperstein-Sonnenschein Model".

In his talk Dr. Ihl gave an example of a Magnetic Catalysis in the Kuperstein-Sonnenschein model. He began his talk with a brief introduction to the Kuperstein-Sonnenschein model of Chiral symmetry breaking. He clarified the basic advantages and disadvantages of the model compared to the Sakai-Sugimoto model. He then moved to describing the back reaction of flavour branes in this set up. Finally he reported an example of a Magnetic Catalysis.

This talk gives another example of Magnetic Catalysis confirming the universal nature of this effect.

The last talk was given by Dr. Stefano Kovacs from Dublin Institute for Advanced Studies. The title was "Membranes in the AdS₄/CFT₃ correspondence"

In his talk Dr. Kovacs reported about his recent study of the M-theory regime of the AdS₄/CFT₃ correspondence. He considered large angular momentum membrane states and identified the corresponding operators in the dual 1+2 d CFT using the proposed ABJM conjecture. He compared the spectrum of fluctuations of the membranes to the conformal dimensions of the corresponding operators. He found that the spectrum of fluctuations matches the spectrum of conformal dimensions.

The abstract nature of his talk contributed to the variety of the topics covered at the meeting and was very well accepted by the audience.

3 Assessment of Results and Impact

The meeting was a response to the large number of papers written on the subject. The objective was to bring together researchers actively working on the holographic approach to Magnetic Catalysis of Chiral Symmetry Breaking and present the latest developments in this area in order to grasp the unified picture of the subject.

I believe that the variety and novelty of the topics covered during the meeting was essential in shaping the future development of this area of the holographic studies. The meeting was also very successful in bringing together researchers working on both high energy and condensed matter applications of the AdS/CFT correspondence in the context of Magnetic Catalysis. The meeting gave opportunity to young researchers (one of them graduating Ph.D. student) to present their work to a wider audience. It also attracted some senior researchers which contributed to the high quality of the topics covered. The discussions following the talks stimulated exchange of ideas which was very beneficial for the participants. In addition the personal contacts established between the participants of the meeting will facilitate a future exchange of ideas which will certainly have a positive impact on the quality of their research.

Another impact that the meeting had was to promote holography to the local scientific community, which is one of the main goals of the Holograph network. In days of scarce public spending in Ireland the funds provided by ESF were highly appreciated by the Dublin scientific community. During the course of the event the meeting was open to local researchers many of whom benefited from the talks and the following discussions. Overall I believe that this event takes an important place in the scientific calendar of 2012.

Finally all talks as well as the program of the meeting are available at the website of the meeting: <http://www.stp.dias.ie/hmccsb2012/> . This makes the event useful even for researchers who were unable to attend the meeting. It also serves as a reference to the participants.

4 List of Participants

1. Braun Volker , Dublin Institute for Advanced Studies
2. Bolognesi Stefano, The Hebrew University of Jerusalem
3. Dolan Brian, NUI Maynooth
4. Evans Nick, University of Southampton
5. Filev Veselin, Dublin Institute for Advanced Studies
6. Frolov Sergey, Trinity College Dublin
7. Ihl Matthias, Dublin Institute for Advanced Studies
8. Jokela, Niko, University of Santiago de Compostela
9. Kalaydzhyan Tigran, DESY & Universitt Hamburg
10. Kaltenbrunner Thomas, Dublin Institute for Advanced Studies
11. Kim Keun-Young, University of Amsterdam
12. Kovacs Stefano, Dublin Institute for Advanced Studies
13. Leitner Marianne, Trinity College Dublin & DIAS
14. Lippert Matthew, University of Amsterdam
15. McLoughlin Tristan, Trinity College Dublin
16. Nahm Werner, Dublin Institute for Advanced Studies
17. O'Connor Denjoe, Dublin Institute for Advanced Studies
18. Schmitt Andreas, Vienna University of Technology
19. Semenov Gordon, University of British Columbia
20. Smits Olaf, Dublin Institute for Advanced Studies
21. Vachovski Martin, Dublin Institute for Advanced Studies
22. Zoakos Dimitrios, University of Porto

Holography and Magnetic Catalysis of Chiral Symmetry breaking

DIAS, 19-21 November 2012

Sunday 18 November

all day	Arrivals
---------	----------

Monday 19 November

9:30-10:00	Welcome and Opening
------------	---------------------

10:00-11:00	Brian Dolan: "Electromagnetic duality in AdS/QHE: magnetic monopoles and the quantum Hall effect"
-------------	---

11:00-11:30	Discussions, Coffee, Cookies
-------------	------------------------------

11:30-12:30	Kim Keun-Young: " μ -T-E phase diagram of the D3/D7(D5) holographic dual at finite B"
-------------	---

12:30-14:00	Lunch Break
-------------	-------------

14:00-15:00	Nick Evans: "Novel Phase Transitions In 3d & 4d"
-------------	--

15:00-15:30	Discussions, Coffee, Cookies
-------------	------------------------------

15:30-16:30	Tigran Kalaydzhyan: "Magnetic catalysis in an expanding quark-gluon plasma and on the lattice"
-------------	--

16:30-18:00	More Discussions, More Coffee, More cookies and Dinner plans
-------------	--

Tuesday 20 November

10:00-11:00	Gordon Semenoff: "Magnetic Catalysis in Graphene"
-------------	---

11:00-11:30	Discussions, Coffee, Cookies
-------------	------------------------------

11:30-12:30	Stefano Bolognesi: "Holographic Magnetic Catalysis from bottom-up"
-------------	--

12:30-14:00	Lunch Break
-------------	-------------

14:00-15:00	Andreas Schmitt: "Inverse Magnetic Catalysis"
-------------	---

15:00-15:30	Discussions, Coffee, Cookies
-------------	------------------------------

15:30-16:30	Niko Jokela: "Towards magnetic catalysis in flavored ABJM"
-------------	--

16:30-18:00	More Discussions, More Coffee, More cookies and Dinner plans
-------------	--

Wednesday 21 November

10:00-11:00	Matthew Lippert: "Brane models of 2+1-dimensional fermions"
-------------	---

11:00-11:30	Discussions, Coffee, Cookies
-------------	------------------------------

11:30-12:30	Dimitrios Zoakos: "Unquenching the Holographic Magnetic Catalysis"
-------------	--

12:30-14:00	Lunch Break
-------------	-------------

14:00-15:00	Matthias Ihl: "Magnetic Catalysis in the Backreacted Kuperstein-Sonnenschein Model"
-------------	---

15:00-15:30	Discussions, Coffee, Cookies
-------------	------------------------------

15:30-16:30	Stefano Kovacs: "Membranes in the AdS ₄ /CFT ₃ correspondence"
-------------	--

16:30-18:00	Discussions, Coffee, cookies and Good bye
-------------	---

Thursday 22 November

all day	Departures
---------	------------