

The research proposal “Applications of the gauge-gravity duality” aims at exploring and extending the uses of the AdS/CFT correspondence in understanding strongly coupled systems and hydrodynamics. In particular, the proposal seeks to promote the use of the AdS/CFT correspondence in three distinct directions.

1. Probing strongly coupled gauge theories.
2. Developing the relation between hydrodynamics and gravity.
3. Uncovering novel condensed matter-like phenomenon in low temperature, non-zero density phases of gauge theories.

The AdS/CFT correspondence, also known more generally as “the gauge-gravity duality”, is a strong-weak duality which relates gravity in  $d+1$  spacetime dimensions to gauge theory in  $d$  dimensions. The canonical example of the AdS/CFT correspondence is the duality between the planar limit of strongly coupled  $N=4$  super Yang-Mills theory and classical type IIB supergravity.

The first objective in this proposal is an attempt at addressing various aspects of quantum chromodynamics (QCD) by means of AdS/CFT technology. One of the challenges QCD poses is that it is described by a strongly interacting quantum theory of which we have little theoretical control over. While it is not expected that the gauge-gravity duality will precisely solve problems in QCD it is expected that some control may be maintained over some of the questions that QCD poses: the location of the QCD critical point and the short thermalization time of QCD.

Successful completion of this part of the proposal will allow us to gain a better handle over the behavior of QCD at high temperatures and non zero densities and also improve the wealth of techniques we possess in solving such systems.

Preliminary work on the first objective was carried out during the first year of the project by I. Itkin. I Itkin began calculating a possible critical point similar to the one conjectured to exist in QCD but in an analog system which is under more theoretical control. While the preliminary findings of I. Itkin looked promising interest in this project has thinned out due to exciting findings in the other two objectives.

The second objective of this proposal aims at studying the relation between hydrodynamics and gravity. Indeed, one of the most encompassing results which have emerged from the gauge-gravity duality has been the enhanced understanding of the role of anomalies in hydrodynamics. In this respect the research program aims at understanding the role of anomalies and parity violation on hydrodynamics behavior via the AdS/CFT correspondence.

One of the findings in this direction is a complete classification of hydrodynamic transport coefficients in  $2+1$  dimensional systems and their explicit realization in the context of the gauge-gravity duality. This work has opened the doorway to an understanding of the behavior of such transport phenomenon in non relativistic systems.

Perhaps of more significance is the recent uncovering of the cohomological structure of transport associated with anomalies in even dimensional field theories. The results of this line of research have revealed that all transport terms associated with even dimensional field theories can be encoded in a certain, particular, type of “thermal anomaly polynomial” with very intriguing properties.

It is expected that further study of this particular research direction will allow for a tight connection between mathematics, gauge theories and hydrodynamics with applications whose implications may potentially range from astrophysics to cohomology theory.

Indeed, there are already several recent works which attempt to tie an astrophysical phenomenon referred to as pulsar kicks to anomalies. Pulsar kicks refer to the kick a pulsar presumably receives when it is formed by core collapse

supernova. It is possible that the hydrodynamic description of theories with anomalies, tied to neutrino emission, can accommodate for such kicks. This is a new and interesting idea that may impact the fields of astrophysics, hydrodynamics and particle physics.

Another research direction associated with is the analysis of universal relations among second order transport coefficients, namely,

$$4\lambda_1 + \lambda_2 = 2\eta\tau_\pi,$$

which was discovered using the gauge-gravity duality. Since this relation seems to be universal for theories with a holographic dual and a 2-derivative action, it holds the promise of teaching us something about second order transport properties of relativistic fluids.

A particularly interesting result, associated with this research direction is the computation of the above linear relation in the context of Gauss-Bonnet gravity. In a recent publication we have shown that the linear relation among second order transport coefficients holds even in the presence of a Gauss-Bonnet term which is introduced perturbatively. Work has been carried out to tackle this problem in the context of full nonlinear Gauss-Bonnet gravity. In the full Gauss-Bonnet theory this linear relation does not hold. This ties in with some parallel work of other groups which have discovered that Gauss-Bonnet theory should only be considered perturbatively.

There are various other directions in hydrodynamics which we are now attempting to address which are associated with the gauge-gravity duality, the most promising direction being the appearance of an inverse cascade in 2+1 dimensional turbulence. The difference between the behavior of turbulence in 2+1 dimensions and higher dimensions should have an impact on the dynamics of AdS4 spacetimes relative to higher dimensional AdS spacetimes. Several attempts at tackling this problem are currently underway. In particular, we have recently gained many results and intuition by taking the number of spacetime dimensions to infinity while keeping translation invariance in most of the dimensions. In this configuration it turns out that the Einstein equations simplify and one finds that the event horizon acts as a fluid in a precise way. It thus opens the doorway to geometrizing the nature of turbulence using geometry.

Our third objective has to do with novel condensed-matter like phenomenon in gauge theories with a dual description. In the original proposal, two research directions were discussed: to mimic the phase structure of holographic superconductors and to study Landau-Ginzburg theory using holographic methods.

In attempting to uncover novel condensed-matter like phenomenon in holographic theories our research has taken a turn to the study of modulated phases of gauge theories. In recent years it has become evident that anomalous gauge theories with a holographic dual can spontaneously form spatially modulated phases. Over the last year we have worked on improving our understanding of such phases by computing two-point functions in such phases and the associated transport properties. Here, we have observed the striking result that the shear-viscosity to entropy ratio of such theories, thought to be universal, is spatially modulated. The latter result may open a connection to various modulated condensed matter phases which are explored in the literature.

The current state of the art in this context is the study of other possible equilibrated phases of matter in the presence of anomalies. Using techniques of gravity in a large (infinite) number of dimensions, we are finding that there may be other non homogenous phases of matter which are possibly of lower free energy than modulated phases. Successful completion of this project may open new doorways to new relations between condensed matter systems and high energy physics.

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