Quark anti-quark entropic force and diffusion constant in a Yang-Mills like theory

S. Tahery and J. Sadeghi

Sciences Faculty, Department of Physics, University of Mazandaran, 47416-95447, Babolsar, Iran
E-mail: s.tahery@stu.umz.ac.ir, pouriya@ipm.ir

ABSTRACT: The entropic force experienced by a moving quarkonia in a plasma, is computed in a hyperscaling violation background by holography approach. In that case, the axis of the moving quarkonia has an arbitrary angle with wind. We use the results for HSV parameters which obtained in our paper [1] as appropriate values satisfying condition $\text{Im} V_{QQ} < 0$. We will show that, in this background the entropic force of the meson shows a decreasing behaviour corresponds to increasing dissociation length. Results of this paper are in agreement with our mentioned work. In addition we will find diffusion constant in an exact case and by an exact approach [2] which satisfies the mentioned condition in there.

KEYWORDS: entropic force, shear diffusion, moving quarkonia in a plasma, hyperscaling violation, dissociation of a meson
1 Introduction

Studying of $Q\bar{Q}$ interaction needs the effect of the medium in the motion of the pair to be considered. Because this pair is not produced at rest in strongly coupled quark gluon plasma (QGP), the velocity of the pair through the plasma has some effects on its interactions that should be taken into account. The interaction energy has a finite imaginary part at finite temperature that can be used to estimate the thermal width of the quarkonia \cite{3,4}. Calculations of $\text{Im}V_{Q\bar{Q}}$ relevant to QCD and heavy ion collisions were performed for static $Q\bar{Q}$ pairs using pQCD \cite{5} and lattice QCD \cite{6,7,8} before AdS/CFT. Melting of heavy quarkonium is one of the main experimental signatures of the formation of QGP \cite{9}. The AdS/CFT is a correspondence \cite{10,11,12,13} between a string theory in AdS space and a conformal field theory in physical space-time. This theory describes the phenomenology of hadronic properties and demonstrate their ability to incorporate such essential properties of QCD as confinement and chiral symmetry breaking. The study of the moving heavy quarkonia in space-time with AdS/QCD approach plays important role in interaction energy \cite{14,33,34,35}. One of the most important works was done by J. Noronha et al where they carried out the imaginary potential for $N = 4$ SYM theory in \cite{18}. One another important quantity in study of $Q\bar{Q}$ is entropic force which is responsible to dissociate the quarkonium, because according to it’s definition entropic force is a force which drives the system towards the state with a larger entropy \cite{19}, in addition the entropic force may be responsible for gravity \cite{20} that we will not discuss here and interested reader can refer to the appropriate reference. So, growing of the entropy $S$ with the inter-quark distance $L$ gives the entropic force as we
will study in this paper. Dissociation of the quarkonium is related to its entropic force[21], it has been argued in lattice QCD studies such as [22–24].

Here we discuss about gravity dual of QCD. Can we have an exact gravity dual of QCD? One can close to it to some extent [29]. What people do, is to start by considering $N = 4$ SYM theory, which at long distances the theory reduces to pure Yang-Mills theory. But there are some differences between this YM theory and the gauge theory dual to the original $N = 4$ theory. Although the vacua of QCD and $N = 4$ SYM theory have very different properties $N = 4$ SYM at $T \neq 0$ with QCD $T > T_c$ (temperature $T_c$ of the crossover from a hadron gas to quark-gluon plasma), many of the qualitative distinctions disappear or become unimportant.

It is interesting to study hydrodynamic behaviour of a meson by considering a meson in a HSV background. In a wide variety of strongly coupled quantum field theories, viscosity makes a bound [30] which has been studied by holography [31]. In many of these theories, the shear viscosity $\zeta$ satisfies $\zeta = \frac{1}{4\pi}$. In [2] the authors mentioned that from approach of [32] one can study diffusion phenomenon with universal behaviour of the diffusion constant. They found exact relation for HSV parameters by holography approach. Proceeding by considering special cases they found exact condition on $d$, $\theta$ and $z$ parameters which can be used to have diffusion constant.

The investigation of moving heavy quarkonia in a space-time plays an important role in the interaction energy [33–36] by AdS/QCD approach. The non-relativistic bound states in a moving thermal bath has been studied by [37]. On the other hand the heavy Quarkonium moving in a Quark-Gluon Plasma is another interesting work which has been studied by [38, 39]. Here we note that the different metric backgrounds lead us to face various effects of interaction energy. The evaluation of $\text{Im} V_{\bar{Q}Q}$ will yield to determine the suppression of $Q\bar{Q}$ in heavy ion collision [40]. On the other hand the effects of deformation parameter in the thermal width of moving quarkonia in plasma has been studied in [41]. Also the imaginary part of the static potential has been studied as an observable and moving quarkonia in strongly coupled anisotropic plasma [42–44]. Here, in order to have $\text{Re} V_{\bar{Q}Q}$ and $\text{Im} V_{\bar{Q}Q}$ for $Q\bar{Q}$ in a plasma we use boosted frame [45]. From bottom-up and top-down approaches and some gauge gravity dualities one can study the behaviour of some parameters in the corresponding theory. By bottom-up approach we consider different metric backgrounds and study the behaviour of some parameters in the thermal width of a moving quarkonia in plasma. One interesting case is considering metrics which are dual to the field theories and are scale invariant but not conformally invariant. As we know such corresponding metrics have a Lifshitz (with hyperscaling violation) scaling symmetries at quantum critical points and a dynamical critical exponent called $z$. We note that the behaviour of the system with hyperscaling violation metric backgrounds near to phase transition, is characterized by the critical exponent $z$. Also we know that the time and space in such background will be scaled differently. So the corresponding metric is not invariant under the mentioned scaling. Here $d – \theta$ plays the role of an effective dimensional space in the dual field theory [46, 47], and theories with hyperscaling violation are intrinsically non-relativistic. With all above explanations, we organize the paper as follows.

In section 2, we will review hyperscaling violation metric background and results of our
last paper. Then we apply the case with relevant parameter which we found in our paper [1] in HSV metric to find entropic force for a moving dipole in section 3, so we can have a comparison between the results of two papers about meson dissociation.

In section 4 we will calculate diffusion constant in our candidate HSV case. Section 5 is about our conclusion and results.

2 Review of thermal width in a hyperscaling violation metric background

As we mentioned before, this paper is in continue of [1], so it is highly recommended to have a review on that. But since in current work we just apply that result to find entropic force in an exact case of hyperscaling violation background, who are not interested in thermal width, can skip from the mentioned paper and consider the review on what we have done as follows.

2.1 Review on hyperscaling violation background

In this section we review hyperscaling violation (HSV) metric background. Such a metric background is scale invariant but not conformally invariant. We consider the following metric,

\[ ds^2 = \frac{1}{r^{2z}} dt^2 + \frac{1}{r^2} (dr^2 + dx_i^2), \] (2.1)

which is invariant under scaling \( t \rightarrow \lambda^z t, \quad x_i \rightarrow \lambda x_i, \) and \( r \rightarrow \lambda r. \) These metrics are exact solutions to gravitational theories coupled to an appropriate matter, with an abelian gauge field in the bulk. By including an abelian gauge field and scalar dilaton, one can construct the full class of metrics [48–60], so which is given by,

\[ ds^2_{d+2} = r^{-2\frac{d-\theta}{d}} (-r^{-2(z-1)} dt^2 + dr^2 + dx_i^2), \] (2.2)

where \( z \) and \( \theta \) are dynamical critical exponent of hyperscaling violation metric [61]. As mentioned before, this metric is not scale invariant under above scaling. So, if we consider some finite temperature in this theory we have to account some \( f(r) \) in the corresponding metric which is given by the following equation,

\[ ds^2_{d+2} = e^{2A(r)} (-e^{2B(r)} f(r) dt^2 + \frac{dr^2}{f(r)} + dx_i^2). \] (2.3)

Then the temperature is proportional to a power of \( r_h \) and for general \( A(r) \) and \( B(r) \) the temperature also depends on them. Moreover, in the gravity side we should take \( r_F < r_h \) and \( r_F \) is the inverse scale of the Fermi surface. In order to have black hole solution we have to consider following background [62],

\[ ds^2_{d+2} = \frac{R^2}{r^2} \left( \frac{r}{r_F} \right)^{2\theta} (-r^{-2(z-1)} f(r) dt^2 + \frac{dr^2}{f(r)} + dx_i^2), \] (2.4)

with \( f(r) = 1 - (\frac{r}{r_h})^{d+z-\theta}, \) \( r_F < r_h \) and the temperature will be as \( T = \frac{1}{4\pi} \frac{|d+z-\theta|}{r_h}. \) Here we note that the the Null Energy condition imposes \((d-\theta)(d(z-1) - \theta) \geq 0, \quad (z-1)(d + z - \theta) \geq 0 [63]. \)
2.2 Review on results of thermal width of a meson in hyperscaling violation background

One important constraint on thermal width is negativity of $ImV_{QQ}$. It means that in QCD system the imaginary part of potential shows the decay behaviour and the corresponding potential should be negative. Keeping this condition in mind, we found imaginary part of potential for a moving meson in plasma by holography approach with a parametric HSV background. On the other hand there are some string solutions for such background could be used in a gravity side of gauge/gravity duality approach. By checking them to know if they satisfy $ImV_{QQ} < 0$, we found two special cases of the hyperscaling violation metric background parameters as, $z = 1$, $\theta = 4$, $d = 1or2$ and $z = 0$, $\theta = 3$, $d = 1or2$ where both categories satisfy the mentioned condition. We have shown that hyperscaling violating metric is very close to a YM theory at finite temperature with suitable $d$, $z$ and $\theta$. Thereafter, the thermal width of a moving meson in a plasma was shown by this metric. Briefly, this is what has been done in [1]. We have some interesting results which can be compared with entropic force, since both thermal width and entropic force are responsible for thermal dissociation.

3 Entropic force of a moving dipole in HSV background

We start with HSV metric background and derive the entropic force relation for a meson which is moving perpendicular in a plasma with rapidity $\xi$. Then we apply it for $z = 1$, $\theta = 4$ and $d = 2$ case.

3.1 Perpendicular case

We have a meson with velocity perpendicular to the wind and rapidity $\xi$ in the plasma then we can assume the pair is at rest and the frame is moving in reverse direction with $-\xi$ [45]. We continue with hamiltonian to find inter-quark distance length as,

$$H(r) \equiv \sqrt{\tilde{V}(r) \tilde{V}(r) - \tilde{V}(r_c)^2},$$

with this definition,

$$\tilde{M}(r) \equiv g_{00}g_{rr} \cosh^2 \xi - g_{xx}g_{rr} \sinh^2 \xi,$$

$$\tilde{V}(r) \equiv g_{00}g_{xx} \cosh^2 \xi - g_{xx}^2 \sinh^2 \xi.$$  \hspace{1cm} (3.2) \hspace{1cm} (3.3)

Where $g_{00}$, $g_{xx}$ and $g_{rr}$ are components of the corresponding metric and $\tilde{V}$ means $V(r_c)$ and $c$ is the deepest position of the string in the bulk.

The equation of motion and the boundary conditions of the string relates $L$ (length of the line joining both quarks) with $r_c$ as follows,

$$\frac{L}{2} = -\int_{r_c}^{\infty} \frac{dr}{H(r)},$$

\hspace{1cm} (3.4)
As we mentioned before, the entropic force has been defined as the entropy $S$ which grows with the inter-quark distance $L$. So we have entropic force as,

$$F = T \frac{\partial S}{\partial L}, \quad (3.5)$$

where $T$ refers to temperature of the plasma. Then one can calculate the entropy as,

$$S = - \frac{\partial F}{\partial T}. \quad (3.6)$$

Now there are two suppositions in here, first for large values of inter-quark distance, where it becomes larger than the maximum value of $LT$ (which we call $c'$), therefore the quarks are completely screened because the fundamental string is breaking in two pieces. The second one means that the fundamental string is connected yet and $LT$ is smaller than $c'$.

If $L > \frac{c'}{T}$ free energy is not unique and it depends on configuration of strings, so from [64] we choose it as,

$$F^{(1)} = \frac{1}{\pi \alpha'} \int_{r_h}^{\infty} dr. \quad (3.7)$$

According to (3.6), we get numeric result as,

$$S^{(1)} = \sqrt{\lambda} \Theta (L - \frac{c'}{T}), \quad (3.8)$$

where $\Theta$ is mathematical theta function, and the entropy of moving quarkonium for large distance of $L$, is similar to the static case which have been considered in many references [65, 66] so we skip from this step and proceed by the second case.

If $L < \frac{c'}{T}$, the free energy which is derived from the on-shell action of the fundamental string in the dual geometry is as follows,

$$F^{(2)} = \frac{1}{\pi \alpha'} \int_{r_e}^{\infty} dr \sqrt{\frac{M(r)V(r)}{V(r) - \frac{V_c}{\xi}}} \quad (3.9)$$

**Considering $z = 1, \theta = 4$ and $d = 2$**

By considering $z = 1, \theta = 4$ and $d = 2$, which behave very close to YM theory[1], we will find entropic force. In addition, note that $\xi$ should be very small [1]. From (3.4), (3.5), (3.6) and (3.9), we follow our studying.

In figure (1) the entropic force of a moving meson in plasma has been considered. We have shown that in small rapidity according to the condition obtained in [1]. One can see the entropic force has a decreasing behaviour corresponds to increasing thermal width and increasing dissociation length of the pair. These results are in agreement with each other.
3.2 Arbitrary angles

In this section we extend our calculations for arbitrary angles, it means that orientation of the dipole can have any arbitrary angle with respect to the velocity vector. $\alpha$ is the angle of the dipole with respect to the $X_{d-1}$ and the dipole is on the $(X_1, X_{d-1})$ plane. From the boundary conditions and the action, constants of motion can be found. Proceeding by them the following relation will result,

$$\frac{L}{2} \cos \alpha = -K \int_{r_c}^{A} dr \sqrt{\frac{M(r) \cosh^2 \xi - N(r) \sinh^2 \xi}{V(r) \left( (V(r) - K^2) \left( V(r) \cosh^2 \xi - P(r) \sinh^2 \xi \right) - V(r)q^2 \right)}}.$$

(3.10)

It is worth noting that the exact derivation of above calculations can be found in [40] in detail. Now, we are going to extend the previous discussion about the entropic force when meson is moving with the velocity which has arbitrary angle with respect to the wind. According to what we mentioned before, there are two suppositions: the first one when quarks are completely screened and we have a large value of inter-quark distance length. In that case according to (3.7) the free energy does not depend on the angle of velocity with respect to the wind. Therefore the corresponding entropic force will be same as last section. But when fundamental string is connected yet and $LT$ is smaller than its maximum value, the free energy is,

$$F^{(2)} = -\frac{T}{\pi \alpha'} \int_{r_c}^{A} dr \sqrt{\frac{V(r) \left( M(r) \cosh^2 \xi - N(r) \sinh^2 \xi \right) \left( V(r) \cosh^2 \xi - P(r) \sinh^2 \xi \right)}{\left( (V(r) - K^2) \left( V(r) \cosh^2 \xi - P(r) \sinh^2 \xi \right) - V(r)q^2 \right)}}.$$

(3.11)

Considering $z = 1$, $\theta = 4$ and $d = 2$ in arbitrary angle case

By considering $z = 1$, $\theta = 4$ and $d = 2$, we extend our studying for arbitrary angle of the pair with wind. Again note that $\xi$ should be very small [1]. From (3.10) and (3.11), we follow our studying. In figure (2) the entropic force of a moving meson in plasma has been considered. We show it in small rapidity according to the condition obtained in [1]. One

![Figure 1. Entropic force of a moving meson in our candidate HSV background, with small rapidity and perpendicular velocity vector to the joining axis of the pair.](image)
can see the entropic force has a decreasing behaviour corresponds to increasing thermal width and increasing dissociation length of the pair. These results are in agreement with each other.

![Figure 2](image.png)

**Figure 2.** Entropic force of a moving meson in our candidate HSV background, with small rapidity and arbitrary angle of velocity vector with joining axis of the pair.

## 4 Diffusion constant in a HSV background

Entropy density is related to shear viscosity $\eta$, by the relation \( \frac{\eta}{s} = \frac{1}{4\pi} \) for a wide variety of theories. By using holographic approach in HSV gravity duals, it is interesting to study hydrodynamic behaviour showed by diffusion constant.

There are another category of the exact values of hyperscaling violation background as \( d, z, \theta = 2, 0, 3 \) found by condition \( \text{Im} V_{QQ} \) in [1], implies that there are such parameters in Lifshitz-like theories lead to a YM-like theory which satisfy thermal width condition for a slowly moving meson in a plasma in limit \( r_c \to r_h \). As we used the first category in last sections to find entropic force in a YM like theory with HSV background, we will study diffusion constant with exact relation found in [2] for \( d - z - \theta = -1 \).

### 4.1 Diffusion constant in case \( d - z - \theta = -1 \)

The main idea is to use approach of [2] to consider the diffusion constant in HSV backgrounds. From there in case hyperscaling violation background parameters satisfy \( d - z - \theta = -1 \) one finds diffusion constant as,

\[
D = r_0^{d-\theta-1} \log\left( \frac{r_h}{r_c} \right) = r_0^{z-2} \log\left( \frac{r_h}{r_c} \right).
\]  

(4.1)

So, with \( d, z, \theta = 2, 0, 3 \) and in limit \( r_c \to r_h \), we arrive at,

\[
D = 0,
\]  

(4.2)

which shows there is hydrodynamical equilibrium in system.

So briefly, in a YM-like theory described by a HSV gravity dual, system of a very slowly moving meson in a plasma is in equilibrium.
5 Conclusion

We had a comparison between entropic force and thermal width of a moving pair in plasma, since both of them are related to meson dissociation. In [1] the satisfying parameters of hyperscaling violation metric background from viewpoint of condition $\text{Im}V_{QQ} < 0$ have been introduced. In addition from there we know metric with $z = 1$, $\theta = 4$ and $d = 2$ is in agreement with above condition besides such HSV metric behave similar to YM theory. So proceeding by this choice we found entropic force of a slowly moving quarkonia in a plasma.

Entropic force and thermal width are related to thermal dissociation both, therefore studying of them could have interesting results. With this motivation and all above considerations we calculated entropic force in two cases, when velocity vector of meson is perpendicular to joining axis of the pair and then we extended those calculation to arbitrary angles. We considered that entropic force has a decreasing behaviour with length which corresponds to increasing dissociation length. These results are in agreement with [1] which presented suitable HSV candidate similar to YM theory. In addition such system has zero shear diffusion constant which describes an equilibrium.

Acknowledgement

The authors are grateful very much to Fatemeh Razavi for support and valuable activity in numerical calculations and also Zeinab Amoozad for useful discussion.

References

[1] S. Tahery and J. Sadeghi, *The investigation of quark-antiquark potential in plasma with hyperscaling violation background*, J. Phys. G Nucl. Part. Phys 44 (2017) 105001 [arXiv:1509.01309 [hep-th]].
[2] Kedar S. Kolekar, Debangshu Mukherjee, K. Narayan, *Hyperscaling violation and the shear diffusion constant*, Phys. Lett. B, 760 (2016) 86 [arxiv:1604.05092 [hep-ph]].
[3] N. Brambilla, M. A. Escobedo, J. Soto and A. Vairo, *Heavy Quarkonium in a weakly-coupled quark-gluon plasma below the melting temperature*, JHEP, 09 (2010) 038 [arxiv:1007.4156 [hep-ph]].
[4] Y. Guo and M. Strickland, *The imaginary part of the static gluon propagator in an anisotropic (viscous) QCD plasma*, Phys. Rev. D, 79 (2009) 114003 [arxiv:0903.4703[hep-ph]].
[5] M. Laine, O. Philipsen, P. Romatschke and M. Tassler, *Real-time static potential in hot QCD*, JHEP, 0703 (2007) 054 [arxiv:0611300 [hep-ph]].
[6] A. Rothkopf, T. Hatsuda and S. Sasaki, *Complex Heavy-Quark Potential at Finite Temperature from Lattice QCD*, Phys. Rev. Lett. 108 (2012) 162001 [arxiv:1108.1579 [hep-lat]].
[7] G. Aarts, C. Allton, S. Kim, M. P. Lombardo, M. B. Oktay, S. M. Ryan, D. K. Sinclair and J. I. Skullerud, *What happens to the Upsilon and eta_b in the quark-gluon plasma? Bottomonium spectral functions from lattice QCD*, JHEP, 1111 (2011) 103 [arxiv:1109.4496[hep-lat]].
[8] G. Aarts, C. Allton, S. Kim, M. P. Lombardo, S. M. Ryan and J. I. Skullerud, *Melting of P wave bottomonium states in the quark-gluon plasma from lattice NRQCD*, JHEP, **1312** (2013) 064 [arxiv:1310.5467 [hep-lat]].

[9] T. Matsui, H. Satz, *J/psi Suppression by Quark-Gluon Plasma Formation*, Phys. Lett. **B178** (1986) 416.

[10] J. M. Maldacena, *The Large N Limit of Superconformal Field Theories and Supergravity*, Adv. Theor. Math. Phys., **2** (1998) 231 [arXiv: 9711200 [hep-th]].

[11] S. S. Gubster, I. R. Klebanov and A. M. Polyakov, *Gauge Theory Correlators from Non-Critical String Theory*, Phys. Lett. B, **428** (1998) 105 [arXiv: 9802109 [hep-th]].

[12] E. Witten, *Anti De Sitter Space And Holography*, Adv. Theor. Math. Phys, **2** (1998) 253 [arXiv: 9802150 [hep-th]].

[13] O. Aharony, S. S. Gubster, J. M. Maldacena, H. Ooguri and Y. Oz, *Large N Field Theories, String Theory and Gravity*, Phys. Rept, **323** (2000) 183 [arXiv: 9905111 [hep-th]].

[14] A. Vega, I. Schmidt, T. Gutsche and V. E. Lyubovitskij, *Generalized parton distributions in AdS/QCD*, Phys. Rev. D **83** (2011) 036001 [arXiv: 1010.2815[hep-ph]].

[15] M. Strickland, *Thermal Upsilon(1s) and chi_b1 suppression in sqrt(s_{NN}) = 2.76TeV Pb-Pb collisions at the LHC*, Phys. Rev. Lett **107** (2011) 132301 [arXiv:1106.2571[hep-ph]].

[16] M. Strickland and D. Bazow, *Thermal Bottomonium Suppression at RHIC and LHC*, Nucl. Phys. A **879** (2012) 25 [arXiv:1112.2761[nucl-th]].

[17] M. Margotta, K. McCarty, C. McGahan, M. Strickland, and D. Yager-Elorriaga, *Quarkonium states in a complex-valued potential*, Phys.Rev.D **83** (2011) 105019 [arXiv:1101.4651 [hep-ph]].

[18] J. Noronha, A. Dumitru, *Thermal Width of the Υ at Large t Hooft Coupling*, Phys. Rev. Lett, **103** (2009) 152304 [arXiv:0907.3062 [hep-ph]].

[19] K. H. Meyer, G. Susich, and E. Valk, *Elastic properties of rubber-like substances Kolloid Z.*, **59**, (1932) 208.

[20] E. P. Verlinde, *On the Origin of Gravity and the Laws of Newton* JHEP **1104** (2011) 029 [arXiv:1001.0785 [hep-th]].

[21] D. E. Kharzeev, *Deconfinement as an entropic self-destruction: A solution for the quarkonium suppression puzzle?*, Phys. Rev. D **90**, (2014) 074007, [arXiv:1409.2496 [hep-ph]].

[22] O. Kaczmarek, F. Karsch, P. Petreczky and F. Zantow, *Heavy quarkantiquark free energy and the renormalized Polyakov loop*, Phys. Lett. B, **543** (2002) 41 [arXiv:0207002 [hep-lat]].

[23] O. Kaczmarek and F. Zantow, *Static quark anti-quark interactions at zero and finite temperature QCD. II. Quark anti-quark internal energy and entropy*, Phys. Rev. D, **71** (2005)114510 [arxiv: 0506019 [hep-lat]].

[24] P. Petreczky and K. Petrov, *Free energy of a static quark anti-quark pair and the renormalized Polyakov loop in three flavor QCD*, Phys. Rev. D, **70** (2004) 054503 [arxiv:0405009 [hep-lat]].

[25] Z-q. Zhang, C. Ma, D-f. Hou, G. Chen *Entropic destruction of a rotating heavy quarkonium*, [arxiv:1611.08011[hep-th]].

[26] Z-q. Zhang, D-f. Hou, G. Chen *The effect of chemical potential on imaginary potential and...*
entropic force, Phys. Lett. B, 768, (2017) 180 [arXiv:1612.08826 [hep-th]].

[27] A. Adare et al. [PHENIX Collaboration], J/ Production vs Centrality, Transverse Momentum, and Rapidity in Au+Au Collisions at $p_{NN} = 200$GeV, Phys. Rev. Lett. 98 (2007) 232301 [arXiv: 0611020 [nucl-ex]].

[28] B. B. Abelev et al. [ALICE Collaboration], Centrality, rapidity and transverse momentum dependence of J/ suppression in Pb-Pb collisions at $p_{NN} = 2.76$TeV, Phys. Lett. B, 734 (2014) 314 [arXiv:1311.0214 [nucl-ex]].

[29] E. Witten, Anti-de Sitter space, thermal phase transition, and confinement in gauge theories, Adv. Theor. Math. Phys. 2 (1998) 505, [arXiv:9803131 [hep-th]].

[30] P. Kovtun, D. T. Son and A. O. Starinets, Viscosity in strongly interacting quantum field theories from black hole physics, Phys. Rev. Lett. 94, (2005) 111601 [arXiv:0405231 [hep-th]].

[31] J.M. Maldacena, The Large N limit of superconformal field theories and supergravity, Int. J. Theor. Phys. 38, (1999) 1113 [Adv. Theor. Math. Phys. 2, 231 (1998)]. [arXiv:9711200 [hep-th]].

[32] P. Kovtun, D. T. Son and A. O. Starinets, Holography and hydrodynamics: Diffusion on stretched horizons, JHEP, 0310 (2003) 064 [arXiv:0309213 [hep-th]].

[33] B. B. Abelev et al. [ALICE Collaboration], Centrality, rapidity and transverse momentum dependence of J/ suppression in Pb-Pb collisions at $p_{NN} = 2.76$TeV, Phys. Lett. B, 734 (2014) 314 [arXiv:1311.0214 [nucl-ex]].
[44] M. Ali-Akbari, D. Giataganas and Z. Rezaei, The Imaginary Potential of Heavy Quarkonia Moving in Strongly Coupled Plasma, Phys. Rev. D 90 (2014) 086001 [arXiv:1406.1994 [hep-th]].

[45] S. I. Finazzo and J. Noronha, Estimates for the Thermal Width of Heavy Quarkonia in Strongly Coupled Plasmas from Holography, JHEP 1311 (2013) 042 [arXiv:1306.2613[hep-ph]].

[46] P. Dey and S. Roy, Lifshitz-like space-time from intersecting space-time, Phys. Rev. D, 86 (2012) 066009 [arXiv:1204.4858[hep-th]].

[47] P. Dey and S. Roy, Lifshitz-like space-time from intersecting branes in string/M theory, JHEP, 06 (2012) 129 [arXiv:1203.5381[hep-th]].

[48] S. S. Gubser and F. D. Rocha, Peculiar properties of a charged dilatonic black hole in AdS5, Phys. Rev. D, 81 (2010) 046001 [arXiv:0911.2898[hep-th]].

[49] K. Goldstein, S. Kachru, S. Prakash and S. P. Trivedi, Holography of Charged Dilaton Black Holes, JHEP, 1008 (2010) 078 [arXiv:0911.3586[hep-th]].

[50] M. Cadoni, G. D’Appollonio and P. Pani, Phase transitions between Reissner-Nordstrom and dilatonic black holes in 4D AdS spacetime, JHEP, 1003 (2010) 100 [arXiv:0912.3520[hep-th]].

[51] M. Cadoni and P. Pani, Holography of charged dilatonic black branes at finite temperature, JHEP, 1104 (2011) 49 [arXiv:1102.3820[hep-th]].

[52] C. Charmousis, B. Gouteraux, B. S. Kim, E. Kiritsis and R. Meyer, Effective Holographic Theories for low-temperature condensed matter systems, JHEP, 1011 (2010) 151 [arXiv:1005.4690[hep-th]].

[53] E. Perlmutter, Domain Wall Holography for Finite Temperature Scaling Solutions, JHEP, 1102 (2011) 013 [arXiv:1006.2124[hep-th]].

[54] G. Bertoldi, B. A. Burrington and A. W. Peet, Thermal behaviour of charged dilatonic black branes in AdS and UV completions of Lifshitz-like geometries, Phys. Rev. D, 82 (2010) 106013 [arXiv:1007.1464[hep-th]].

[55] K. Goldstein, N. Iizuka, S. Kachru, S. Prakash, S. P. Trivedi and A. Westphal, Holography of Dyonic Dilaton Black Branes, JHEP, 1010 (2010) 027 [arXiv:1007.2490[hep-th]].

[56] N. Iizuka, N. Kundu, P. Narayan and S. P. Trivedi, Holographic Fermi and Non-Fermi Liquids with Transitions in Dilaton Gravity, JHEP 01 (2012) 094 [arXiv:1105.1162[hep-th]].

[57] P. Berglund, J. Bhattacharyya and D. Mattingly, Charged Dilatonic AdS Black Branes in Arbitrary Dimensions, JHEP 08 (2012) 042 [arXiv:1107.3096[hep-th]].

[58] N. Ogawa, T. Takayanagi and T. Ugajin, Holographic Fermi Surfaces and Entanglement Entropy, JHEP 01 (2012) 125 [arXiv:1111.1023[hep-th]].

[59] L. Huijse, S. Sachdev and B. Swingle, Hidden Fermi surfaces in compressible states of gauge-gravity duality, Phys.Rev.B.85 .035121 [arXiv:1112.0573[cond-mat.str-el]].

[60] E. Shaghoulian, Holographic Entanglement Entropy and Fermi Surfaces, JHEP 05 (2012) 065 [arXiv:1112.2702[hep-th]].

[61] D. S. Fisher, Scaling and critical slowing down in random field Ising systems, Phys. Rev. Lett. 56 (1986) 416.
[62] N. Iizuka, N. Kundu, P. Narayan and S. P. Trivedi, *Holographic Fermi and Non-Fermi Liquids with Transitions in Dilaton Gravity*, JHEP **01** (2012) 094 [arXiv:1105.1162[hep-th]].

[63] B. Swingle and T. Senthil, *Universal crossovers between entanglement entropy and thermal entropy*, PhysRevB.**87**.045123[arXiv:1112.1069[hep-th]].

[64] D. Bak, A. Karch, L. G. Yaffe, *Debye screening in strongly coupled $N = 4$ supersymmetric Yang-Mills plasma*, JHEP, **0708** (2007) 049 [arXiv:0705.0994 [hep-th]].

[65] Z-q. Zhang, D-f. Hou, G. Chen *The effect of chemical potential on imaginary potential and entropic force*, Phys. Lett. B, **768**, (2017) 180 [arXiv:1612.08826 [hep-th]].

[66] K. B. Fadafan, S. K. Tabatabaei, *Entropic destruction of a moving heavy quarkonium*, Phys. Rev. D, **94**, (2016) 026007 [arXiv:1512.08254 [hep-ph]].