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Holographic Fermi Surface at Finite Temperature

Reena Chahal[1]*, Dr. Pradeep Kumar[2]

[1] Research Scholar, Sunrise University

[2] Assistant Professor, Sunrise University

Abstract - The Gauge/Gravity duality allows us to effortlessly switch between a strongly coupled d-dimensional field theory and a weakly connected d + 1 dimensional gravity theory. The powerful tools made accessible by the holographic duality may be useful in a variety of domains, including as gauge theory, hydrodynamics, and condensed matter theories. The situation of low temperatures has been included to our studies. The examination of the spectrum function of these fermionic modes supports the zero-temperature result. We find that at a certain temperature, only specific modes allow for a Fermi surface in a limiting version of this blackhole background with a single charge. If we extend the analysis performed at zero temperature to the finite temperature situation, we will find the formula for the complete Green's function of the dual theory. In the dual field theory, scalars also have a significant impact on whether or not a black hole with a single charge has a Fermi surface. Since the predicted value of the scalar in the dual fermionic operator is non-zero, we found that the Fermi surface may exist thanks to the presence of dual operators.

Keywords - Holographic, Fermi, Surface, holographic duality and FiniteTemperature

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INTRODUCTION

An intriguing duality between the gauge theory and gravity has been postulated in the previous century. It has been suggested that, in an anti-de Sitter (AdS) space, gauge theories are identical to gravity theory. While the existence of such a connection had previously been hinted at, it was only in that it was made explicitly clear. While a connection between theories with such opposite tenets is a little out of the ordinary, it emerges as a coherent picture due to the facts that both theories hold water under various regimes of coupling constants. The term "gauge/gravity duality" refers to the observation that the highly coupled regime of a gauge theory is dual to the weakly coupled domain of a gravity theory, and vice versa.

Its applicability to broader geometries was quickly recognized after its inception. It is also known as holographic duality because the gravity theory inhabits the (d+1)-dimensional core of the AdS spacetime, while the dual field theory inhabits the (d)-dimensional border of the AdS space. In the field theory, the boundary operators are analogous to the numerous fields found in the bulk of AdS. Applications in fields as disparate as gauge theory, hydrodynamics, condensed matter theory, and more arise from the availability of this holographic duality's potent tools for disentangling and exploring highly coupled regimes.

In this article, we will discuss how this duality may be used to analyze highly coupled systems in condensed matter theories. The conventional perturbative approaches have a limited impact when dealing with tightly correlated systems, and the field theoretic framework has the problem of being too simplistic. Landau presented the Fermi liquid theory as a viable method for dealing with such non-perturbative systems. It characterizes such systems by substituting weakly interacting quasi-particles for electrons. These may be thought of as electrons that have been "dressed" with photons. Due to the low strength of the interactions between the quasi-particles, the perturbative formulation may be used to analyze the system. Up until the 1980s, the Fermi liquid theory did a good job of describing the behaviors of metals and semiconductors. Later on, however, substances were found that defy Fermi liquid theory.

Despite the presence of a Fermi surface, the quasi-particle excitations in cuprate superconductors and heavy fermions are transient and unstable. To confirm the presence of the Fermi surface and the instability of quasi-particles, researchers used angular resolved photoemission spectroscopy (ARPES). Non-Fermi liquid is the term used to describe these substances. The linear temperature dependence of resistivity seen in materials in the weird metal phase is at odds with the T 2 behavior anticipated by the Fermi liquid theory. It becomes evident that the Fermi liquid theory cannot be used to such highly correlated systems, necessitating the development of novel non-perturbative methods. This opens up new problems to be solved and offers a testing ground for the theory of gauge/gravity duality. It turns out that charged black holes offer the essential gravity duals in order to handle the challenges in such finite density systems with finite temperature inside a holographic framework.

Those gravity duals are amenable to the incorporation of fermionic fields, allowing for the study of fermionic excitations in the dual system. Sharp quasiparticle-like fermionic excitations at low energies with scaling behavior distinct from Fermi liquid were discovered in the first holographic study of Fermi surfaces. In, the behavior of such fermionic excitations was analyzed in further detail. They have looked at the dimensions of the dual operators and the scaling exponents of the spectral function in dual field 2 theory. They also discovered that the peak of the spectral function exhibits log periodic behavior and that the Fermi surface occurs throughout a range of momentum beyond which it ceases to exist.

LITERATURE REVIEW

Wahlang, W. (2022), Using Wahlang, W. as an example. We look at a holographic toy model that includes a probe fermion with a finite charge density in an anisotropic background. After doing a numerical calculation of the fermionic spectrum function, we discovered certain peculiarities in the system's Fermi surface (FS) structure and evolution. The action for holographic fermions includes a complex scalar field and non-minimal interaction components, but we neglected to take into consideration the background's effect on the fermions' field. We find that the spectral weight and deformation of FS are reduced, which is similar to the results of previous condensed matter research on real materials.

Paola Zizzi. (2021). In this work, we demonstrate how the Quantum Holographic Principle may be extended to the context of Loop Quantum Gravity, whereby the size of the boundary surface encircling an area of space encodes a qubit per Planck unit. To do this, we use bulk fermion fields with a spherical boundary surface in two dimensions. Since the fermionic degrees of freedom have been doubled thanks to the Bogolyubov transformations, the edges of the spin network may breach the boundary surface in pairs, giving rise to pixels of area that may encode a qubit. Fuzzy spheres are also valid in this proof.

"De Haro, (2016)." We briefly introduce gravity/gravity duality and holography to set the stage. Since Maldacena's AdS/CFT correspondence will serve as our fundamental example, we begin by providing an overview of anti-de Sitter spacetime, conformal field theory, and string theory. Applications to QCD, hydrodynamics, and the aforementioned condensed matter systems are discussed in further detail in Section 6. In sections 8 and 9, the author proposes extending holographic notions to de Sitter spacetime and even black holes. We explore the implications of the gravity/gravity duality on two philosophical questions in Section 10: the belief that spacetime, or at least some parts of it, are emergent, and the view that different physical theories are equivalent.

Johanna Erdmenger, (2021) Insights from nonconformal instances of the AdS/CFT correspondence are used to establish gravity/gravity dual descriptions of explicit realizations of the strong coupling sector of composite Higgs models. For the two gravity theories that have the best lattice data, Sp(4) and SU(4), we determine the masses of particles and the pion decay constants. Since we can tailor the fermion composition to our needs, our findings surpass those of lattice investigations. Its selection alters the kinetics of the system in motion, which may have a significant impact on the masses of the bound states. We employ a dual fermionic field to define the optimal companions. Incorporating appropriate operators in higher dimensions is necessary to guarantee a top mass compatible with the standard model.

Karch, Andreas et.al (2016). Particle-vortex duality in d=2+1 dimensions is easily derived by us. Our starting point is a sort of flux attachment that is both relativistic and intended to alter particle statistics. New dualisms are spun out of this one source. Bosonic particle-vortex duality and its newly found fermionic counterpart are two examples.

GREEN'S FUNCTION

Computing the green's function using AdS/CFT correspondence methods allows us to investigate the counterpart fermionic operators. From this starting point, we may derive the Dirac equations for spin 1/2 fermions. λ^i in this context, the study of Fermi surfaces in the boundary theory of supergravity is fruitful. we get the Dirac equation for the 8 spinors of supergravity. As we saw in the last chapter, these equations may be further reduced. There are eight total components, or spinors, in each spinor. Ψ^i and η^i. By appropriate selection of Γ matrices and choosing t and x dependences

$$\lambda^i = e^{-A(r)} h(r)^{-1/4} e^{-i\omega t + ikx} \begin{pmatrix} \Psi^i \\ \eta^i \end{pmatrix},$$

one can make the four-component

spinors, Ψ^i and η^i to meet the same equational criteria. Regarding this, we'll be focusing only on Ψ^i for the sake of our math as η^i will act in the same way. Each of the four spinor components Ψ^i May be expressed in terms of a pair of spinors with just two components Ψ^i , as follows:

$$\Psi^i = \begin{pmatrix} \Psi_1^i \\ \Psi_2^i \end{pmatrix}, \quad \Psi_\alpha^i = \begin{pmatrix} \Psi_{\alpha-}^i \\ \Psi_{\alpha+}^i \end{pmatrix}, \quad \alpha = 1, 2.$$

If we use this notation, we may write the Dirac equations as (i index has been suppressed)

$$(\partial_r + X\sigma_3 + Yi\sigma_2 + Z\sigma_1)\Psi_\alpha = 0,$$

$$\text{where} \quad X = m\frac{e^B}{\sqrt{h}}M(\phi_1,\phi_2), \quad Y = -\frac{e^{B-A}}{\sqrt{h}}u(r), \quad Z = -\frac{e^{B-A}}{\sqrt{h}}[(-1)^\alpha k - v(r)],$$

$$\text{and} \quad M(\phi_1,\phi_2) = (m_1 e^{2\phi_1} + m_2 e^{2\phi_2} + m_3 e^{-4(\phi_1+\phi_2)})$$

$$u(r) = \frac{1}{\sqrt{h}}[\omega + 2m(q_1 A_t^{(1)} + q_2 A_t^{(2)})]$$

$$v(r) = 2e^{-B}[p_1 e^{-2\phi_1} F_{rt}^{(1)} + p_2 e^{-2\phi_2} F_{rt}^{(2)}].$$

Changing the value of causes a corresponding change in the sign of, as can be seen. k. Therefore, for a given value of α if a system admits a Fermi surface at$k = k_F$, for the other value of α, Fermi surface is at $k = -k_F$, assuming we keep everything else the same. This allows us to choose a value for without sacrificing generality.

These fermions exhibit an oscillating near-horizon behavior. In order to eliminate this oscillatory behavior, we shall propose the following quantities, known as generalized fluxes, in line with. This oscillatory behavior at the near horizon limit may be eliminated by introducing these generic fluxes.

$$U_\pm = \Psi_- \pm i\Psi_+, \quad \mathcal{F} = |U_+|^2 - |U_-|^2$$

$$\mathcal{I} = U_+U_-^* + U_+^*U_-, \quad \mathcal{J} = i(U_+U_-^* - U_+^*U_-), \quad \mathcal{K} = |U_+|^2 + |U_-|^2.$$

It is now possible to express the Dirac equation in terms of these more generalized fluxes; the resulting equations are as follows.

$$\partial_r\mathcal{F} = 0, \quad \partial_r\mathcal{I} = 2Y\mathcal{J} - 2X\mathcal{K},$$

$$\partial_r\mathcal{J} = -2Y\mathcal{I} + 2Z\mathcal{K}, \quad \partial_r\mathcal{K} = -2X\mathcal{I} + 2Z\mathcal{J}.$$

For a given value of α the near horizon behaviour of the fermion fields is given by,

$$\Psi_- = i\Psi_+ = \frac{i}{2}(r - r_h)^{-\frac{i\omega}{4\pi T}},$$

along with corrections of order $\sqrt{r - r_h}$. From we may assess how the generalized fluxes behave close to the horizon. When expanding in X, Y, and Z to the leading order at the near horizon limit, the resulting fluxes are given by.

$$\mathcal{F} = 1, \quad \mathcal{I} = i_1\sqrt{r - r_h}, \quad \mathcal{J} = j_1\sqrt{r - r_h}, \quad \mathcal{K} = 1,$$

(4.2.6)

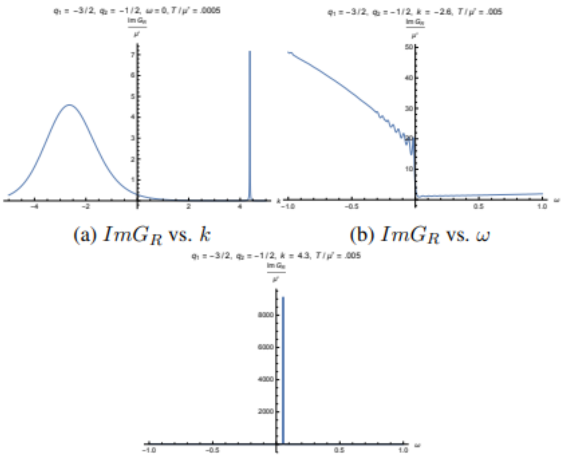
where i_1 and j_1 depends on ω, k, r_h parameters associated with fermions, and so on.

RESULTS

The spectral function associated with the dual fermionic operator in supergravity theory is analyzed in this section. Under a gravitational field of U (1) × U (1), all eight fermions carry charges. Changing the sign and swapping the charge parameters Q1 and Q2 connects the different fermionic modes, as described in [44]. of q_i *and* p_i *associated* with flipping the signs of k and ω. In general, our history includes two charge parameters that are not zero. Q_1 and Q_2. We have only considered two different modes, namely $q_1 = -3/2$, $q_2 = -1/2$ and $q_1 = -3/2$, $q_2 = 1/2$ because the actions of other modes against this backdrop are analogous. These are what we call "two-charge" instances. We derive the spectral function by numerically solving for both modes with the infalling boundary condition ImGR using (4.2.10), throughout the result we will set $m = 2$. We have also investigated the spectral function for single-charged fermions in the general background. One of the charge settings may be adjusted to get this backdrop., $Q_2 = 0$ after which we repeated the preceding steps to analyze the modes using $q_1 = 3/2$, $q_2 = 1/2$and $q_1 = 1/2$, $q_2 = 1/2$.

At T =.0005, we shall now think about the fermionic mode with charges. $q_1 = -3/2$,

$q_2 = 1/2$ which translate to a smaller net charge at absolute zero. For $Q_1^2/r_h^4 = 10$ and $Q_1^2/r_h^4 = 2$ plots are given in Fig. and Fig. respectively. It is clear from the figures that in both the cases it has a single peak, at $k = -.1572$ and at $k = 3.054$ for Q^2/r^4 10 and $Q^2/r^4 = 2$ respectively. At each value of k, the spectral function reaches its maximum for both charge parameters. This maximum occurs at = ω = 0 This mode accepts just one Fermi surface for each scenario since there is only one peak for each value of the charge parameter. Chapter 3 also demonstrates this property in the zero-temperature scenario.



(a) ImG_R vs. k (b) ImG_R vs. ω

(c) ImG_R vs. ω

Figure 1: Spectral function for fermionic mode with $q_1 = -3/2$, $q_2 = -1/2$, $Q^2/r^4 = 10$

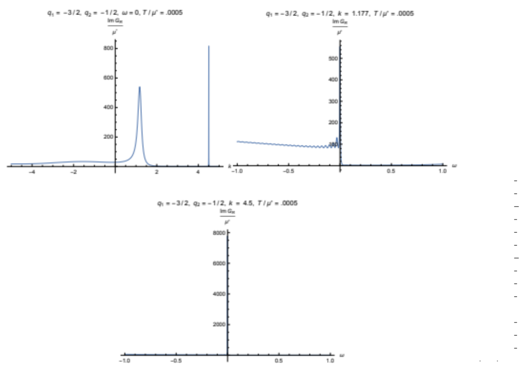


Figure 2: Spectral function for fermionic mode with $q_1 = -3/2$, $q_2 = -1/2$ for $Q^2/r^4 = 2$

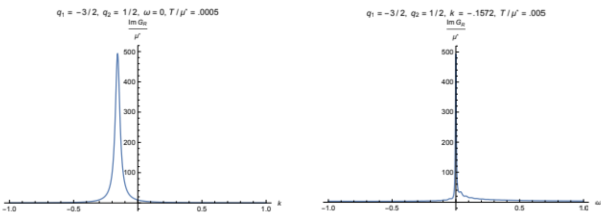


Figure 3: Spectral function for fermionic mode with $q_1 = -3/2$, $q_2 = 1/2$ for $Q^2/r^4 = 10$

We expand our study to one-charge instances by setting one of the charge parameters to zero, Q2 = 0, since we could not discover an extremal limit for such cases at zero temperature. The operator dual of the mode is introduced first. $q_1 = 3/2$, $q_2 = 1/2$, for this case we have plotted spectral function vs. $k$at $\omega = 0$. One can clearly see from Fig. , it shows a peak at around $k = -0.899$. Using k = 0.899, we can plot the spectral function against and see a peak at = ω = 0. . This leads us to believe that a Fermi surface is possible in this mode. Dual to the fermionic mode with q1 = 1/2, q2 = 3/2, the equivalent graphs are shown in Fig, therefore we will also think about those operators. When comparing the spectral function to the. k at $k = 0.451$ but the spectral function vs ω-plot at$k = 0.451$ does not give any peak around $\omega = 0$. This means that there is no Fermi surface for the operator dual to the fermionic mode with charges q1 = 1/2 and q2 = 3/2.

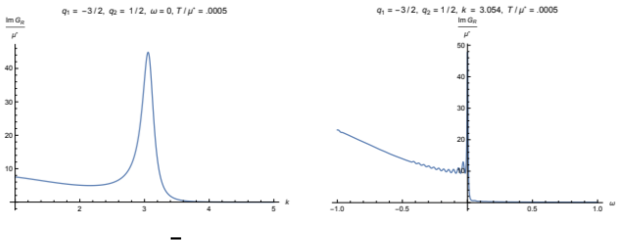


Figure 4: Spectral function for fermionic mode with $q_1 = -3/2$, $q_2 = 1/2$ for $Q^2/r^4 = 2$

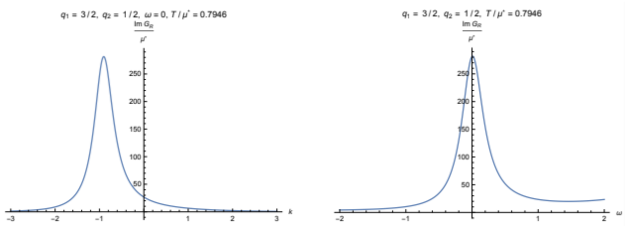


Figure 5: Spectral function $q_1 = 3/2$, $q_2 = 1/2$. Left figure is at $\omega = 0$ and rightfigure is the plot vs. ω..

When there are two charges, the more positively charged fermion is more likely to create a Fermi surface. Operators with gaug-inos from the viewpoint of dual field theory ψ (±1/2, ±1/2) operators involving gaugeons have two Fermi surfaces. ψ (±1/2, ∓1/2) own a unique Fermi surface. The operator's allowed Fermi surface seems to be determined by the gaugeons. We analyze the connection between the dual field theory and string theory to ascertain the significance of scalars in defining the Fermi surface. φ_1 and φ_2 in the scalar operator of the dual field theory and the supergravity. The rotation of phases in our solution is described by the symmetry group U (1) × U (1). $\Sigma^{1\pm}$ and $\Sigma^{2\pm}$ respectively. This means that M 5-branes are distributed in a symmetrical manner in the large N limit. In terms of Σ^i, i = 1, 2, .5(they are related to $\Sigma^{1\pm}$ and $\Sigma^{2\pm}$ through $\Sigma^{1\pm} = \Sigma^1 \pm i\Sigma^2$, $\Sigma^{2\pm} = \Sigma^3 \pm i\Sigma^4$) this means that dual field theory scalar operators satisfy $tr((\Sigma^1)^2) = tr((\Sigma^2)^2)$ and $tr((\Sigma^3)^2) = tr((\Sigma^4)^2)$, which we would refer as $tr\,(\Sigma^2)$ and $tr\,(\Sigma^2)$ respectively,

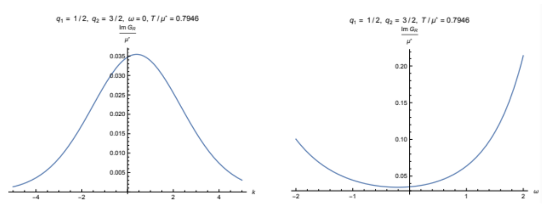


Figure 6: Spectral function $q_1 = 1/2$, $q_2 = 3/2$. Left figure is at $\omega = 0$ and right figure is the plot vs. ω.

while we write $(\Sigma^5)^2 = \Sigma^2$. Due to this symmetry, we may express the dual operators of the supergravity field φ1 and φ2 as

$$\mathcal{O}_{\phi_1} \sim \frac{1}{5} tr(-3\Sigma_A^2 + 2\Sigma_B^2 + \Sigma_C^2) \quad \text{and} \quad \mathcal{O}_{\phi_2} \sim \frac{1}{5} tr(2\Sigma_A^2 - 3\Sigma_B^2 + \Sigma_C^2).$$

For the one-charge instances, where we set, we can see from the asymptotic expansion of φ1 and φ2, provided in the supergravity solution that $Q_2 = 0$, ($O_{\varphi 1}$) is nega- tive and ($O_{\varphi 2}$) is positive. This implies Σ_A, or in other words, $\Sigma^{1\pm}$ has a probability that is greater than zero. Based on our research presented above, we conclude that the involved operators $\Sigma^{1\pm}$ operations leading to the Fermi surface and those involving the $\Sigma^{2\pm}$ not allow entry to anybody. This finding provides support for the idea that the Fermi surface is affected by the expected values of the scalars that occur in the dual operator. N=4 SYM and ABJM models provide the same conclusion It is worth noting that although the models presented in have vanishing zero entropy, the near horizon geometry in the current example is AdS2 with a non-zero entropy at T = 0, thus this property seems to be rather widespread. It is reasonable to infer that both charge parameters are positive when both are non-zero. $\Sigma^{1\pm}$ and $\Sigma^{2\pm}$ have an expectation value greater than zero, resulting in a Fermi surface (or surfaces) for all operators.

CONCLUSION

The entropy density of the backgrounds we investigate vanishes at the proper extremes. When the expectation value of the scalar field in the dual field theory operator is positive, holographic Fermi surfaces are seen, which makes sense given that quasi-particles near these surfaces have non-singlet gauge quantum numbers in the dual field theory. We also addressed the black hole's one-charge limit, which does not have an extremal limit and was thus only explored in the finite temperature regime. In this scenario, a Fermi surface is allowed by the higher-charged (|q1| = 32) Fermion, but not the lower-charged (|q1| = 1/2) one, as determined by analyzing the spectral density.

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Corresponding Author

Reena Chahal*

Research Scholar, Sunrise University