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Gapped fermionic spectrum from a domain wall in seven dimension

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ABSTRACT

We obtain a domain wall solution in maximally gauged seven dimensional supergravity, which interpolates between two AdS spaces and spontaneously breaks a $U(1)$ symmetry. We analyse frequency dependence of conductivity and find power law behaviour at low frequency. We consider certain fermions of supergravity in the background of this domain wall and compute holographic spectral function of the operators in the dual six dimensional theory. We find fermionic operators involving bosons with non-zero expectation value lead to gapped spectrum.

1. Introduction

Gauge-gravity duality [1–3] has been proved to be extremely useful in studying strongly coupled fermionic systems. One can consider a custom gravity theory in accordance with the symmetries of the dual field theory and use the duality to analyse various aspects of the latter. The gravity theory with charged AdS black hole in one higher dimension provides necessary computational techniques to study the fermionic systems. Indeed, it leads to fermionic excitations with scaling behaviour of non-Fermi liquids [4–6]. Subsequently, study of low energy behaviour of the system with constant charge and mass as well as that of relation between scaling exponent and dimension of dual operator in general dimensions appeared in [7]. It was found that turning on dipole coupling beyond a critical value gives rise to dynamically generated gap [8, 9] as found in Mott insulators. Charged Lifshitz black brane with dipole coupling was considered in [10,11], leading to gap around the Fermi surface. Effects of impurity in holographic system were studied in [12] where they found phase transition of fermionic system from non Fermi liquid to Fermi liquid regime.

In addition to this flexible and informative approach, often it is advantageous to adopt the top-down approach where the dual theory is known and variations of parameters within the theory helps to make identification of states in the dual theory. Such an approach was employed to study probe branes and $N = 2$ supergravity theories [13–17]. Though Fermi surface was not found in the case of $N = 2$ supergravity theories [15–17], analyses of maximally symmetric gauged supergravity theories at zero temperature appear subsequently, leading to holographic Fermi surfaces [18–21]. Green's functions of dual operators at finite temperature were also computed for these theories [22,23]. A similar study for gravity background having vanishing entropy at zero temperature [24] reported fermionic fluctuations are stable within a gap around Fermi surface. Related discussions of Fermi surfaces appeared in [25–27].

There is an interesting class of backgrounds on the gravity side, which corresponds to condensation of charged scalar in holographic superconductors and gives rise to spontaneous breaking of $U(1)$ symmetry. Domain wall solutions are natural candidates for zero temperature limit of these backgrounds [28,29]. Study of fermions for such a condensed phase of holographic superconductor at zero temperature [30] shows a spectrum similar to that obtained in APRES experiment. Perhaps it is interesting to understand the mechanism lying behind the appearance of such a gapped spectrum in these cases. [31] considered a study of Majorana fermions with self coupling, coupled to a scalar (with twice charge) and found similar gapped spectrum. Holographic superconductors were constructed from string and M theory [13,32–35] and studies of spectra for these backgrounds appread in literature subsequently. [36] considered generic fermions with a domain wall solution as the background in a four dimensional supergravity, that follows from compactification of M theory. They obtained bands of normalisable modes in the region $\omega^2 < k^2$. Further studies of domain wall solutions with a symmetry breaking source in four dimensional gauged supergravity (dual to Aharony–Bergman–Jafferis–Maldacena (ABJM) theory) [37] shows both gapped and gapless bands of stable excitations. Studies of similar solutions dual to states in ABJM theory with broken $U(1)$ symmetry [38] also reported gapped spectrum. The gaps in the spectra have been attributed to low fermionic charge and particle-hole interaction [38].

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The top-down approach has the advantage that it considers supergravity theories which are low energy limit of string/M theory for which, dual theory is known and holographic dictionary provides identification of operators in the dual field theory with various supergravity modes. Therefore, it provides an arena where one can study role of the dual operators underlying various phenomena and can address the field theory mechanism as well. In this vein, we consider a maximally symmetric gauged supergravity theory in seven dimensions, whose dual theory is a superconformal field theory in six dimensions and the operators dual to the various supergravity modes can be identified [39,40]. Being one of the three maximally superconformal field theories, it is interesting in its own right. Field contents involve a tensor multiplet and symplectic Majorana–Weyl gauginos which are different from theories in three and four dimensions that have been analysed in this context [37,38]. We have obtained a domain wall solution, interpolating between two AdS geometries, in this seven dimensional supergravity. The solution breaks a $U(1)$ of the R-symmetry group spontaneously and thus may correspond to zero temperature of holographic superconductor. We have computed the optical conductivity numerically and find that in the low frequency limit it behaves as $\omega^{2\triangle_B+3}$ for certain constant $\triangle_B$, while for high frequency it goes as ω^3 as expected for ultraviolet AdS_7 geometry. The fermionic content of the supergravity theory consists of 16 spin-1/2 fermions and we have considered only those modes, which do not couple to gravitino. In the background of the domain wall solutions we find there are only four such modes. We have studied spectral function for the operators dual to those modes and find in the spectrum there is a depleted region around $\omega = 0$. We have also artificially dialled the value of the charges up to $q = -2$ to study its effect on the spectrum and find the gap persists. Analysing the dual field theory, we find fermionic operators involving scalars with non zero expectation value, gives rise to gapped spectrum in these cases.

The plan of the article is as follows. In the next section, we describe the domain wall solution and study the optical conductivity. In section 3 we present Green's function while section 4 consists of the numerical result. We conclude with a discussion in section 5.

2. Domain wall solution

We begin with a discussion of bosonic content of the seven dimensional supergravity theory [41–43]. There exists a consistent truncation of eleven dimensional supergravity to this theory with only the lowest massless modes [41] and solution of this theory are expected to remain solution of the full theory, when uplifted [44]. It involves a gauged $SO(5)_g$ and a composite $SO(5)_c$ and consists of a graviton, a Yang–Mills gauge field in adjoint of $SO(5)_g$ and five rank-3 tensors in **5** of $SO(5)_g$. In addition, there are 14 scalar fields, which parameterise $SL(5,R)/SO(5)_c$. The lagrangian is given by,

$$\begin{aligned}2\kappa^2 e^{-1}\mathcal{L}_{boson} &= R + \frac{1}{2}m^2(T^2 - 2T_{ij}T^{ij}) - tr(P_\mu P^\mu)\\ &\quad - \frac{1}{2}(V_I^i V_J^j F_{\mu\nu}^{IJ})^2 + m^2(V_i^{-1I}C_{\mu\nu\rho I})^2\\ &\quad + e^{-1}\bigg(\frac{1}{2}\delta^{IJ}(C_3)_I\wedge(dC_3)_J\\ &\quad + m\epsilon_{IJKLM}(C_3)_I F_2^{JK}F_2^{LM} + m^{-1}p_2(A,F)\bigg)\end{aligned} \tag{2.1}$$

Here $I, J = 1, 2, .., 5$ denote $SO(5)_g$ indices, and $i, j = 1, 2, .., 5$ denote $SO(5)_c$ indices. V_I^i represent fourteen scalar degrees of freedom parametrising $SL(5,R)/SO(5)_c$ coset transforming as **5** under both $SO(5)_g$ and $SO(5)_c$. The tensor T_{ij} is given by $T_{ij} = V_i^{-1\ I}V_j^{-1\ J}\delta_{IJ}$ and $T = T_{ij}\delta^{ij}$. There is a Yang–Mills gauge fields $A_{\mu I}^J$ transforming under adjoint of gauge group $SO(5)_g$ and covariant derivative of V_I^i is given as $\mathcal{D}_\mu V_I^i = \partial_\mu V_I^i - ig(A_\mu)_I^J\ V_J^i$. P_μ and Q_μ are symmetric and antisymmetric parts of the covariant derivative: $V_i^{-1I}\mathcal{D}_\mu V_I^k\delta_{kj} = (Q_\mu)_{[ij]} + (P_\mu)_{(ij)}$. In what follows we will set $C_{3I} = 0$.

The bosonic part of the full theory is quite involved, so we consider a truncation to make it simpler. Since the gauge group $SO(5)$ has rank two we have kept two Cartan gauge fields $A_\mu^{12} = A_\mu^{(1)}$ and $A_\mu^{34} = A_\mu^{(2)}$, while set other components of the gauge fields to be equal to zero. Considering a diagonal scalar vielbein V_I^i will lead to $U(1)^2$ gauge symmetry. Since we are interested in a background that would break one of the $U(1)$, we consider the following ansatz for the scalar vielbein

$$\begin{aligned} V_I^i &= \exp[\phi_2 Y_2]\exp[\phi_1 Y_1 + \phi_3 Y_3], \qquad Y_1 = \mathrm{diag}(1,-1,0,0,0),\\ Y_2 &= \begin{pmatrix} 0 & 1\\ -1 & 0\end{pmatrix}\oplus \mathrm{diag}(0,0,0), \qquad Y_3 = \mathrm{diag}(0,0,1,1,-2),\end{aligned} \tag{2.2}$$

where Y_1, Y_2 and Y_3 are generators of $SL(5)$. For such a choice the bosonic action turns out to be

$$\begin{aligned} 2\kappa^2 e^{-1}\mathcal{L} &= R - \frac{m^2}{2}V(\phi_1,\phi_3) - 2(\partial\phi_1)^2\\ &\quad - 2\sinh^2 2\phi_1(\partial_\mu\phi_2 + gA_\mu^{(1)})^2 - 6(\partial_\mu\phi_3)^2\\ &\quad - (F_{\mu\nu}^{(1)})^2 - e^{4\phi_3}(F_{\mu\nu}^{(2)})^2,\\ \text{where}\quad V(\phi_1,\phi_3) &= -(e^{2\phi_1} + e^{-2\phi_1} + 2e^{-2\phi_1} + e^{4\phi_3})^2\\ &\quad + 2(e^{4\phi_1} + e^{-4\phi_1} + 2e^{-4\phi_3} + e^{8\phi_3}).\end{aligned} \tag{2.3}$$

In the above lagrangian we will set $\phi_2 = 0$ that breaks the $U(1)$ symmetry associated with $A_\mu^{(1)}$. From (2.2) we can observe that this is equivalent to choice of unitary gauge for the coset. From the equations ensuing from the lagrangian (2.3) we can further simplify the action by setting $\phi_3 = 0$ and $A_\mu^{(2)} = 0$. From the equations of motion, that follows from the above lagrangian one can see that these correspond to consistent solution. The potential $V(\phi_1,\phi_3)$ will reduce to

$$V(\phi_1) = (2\cosh 2\phi_1 - 3)^2 - 16. \tag{2.4}$$

The potential (2.4) has extrema at $\phi_1 = 0$ and $\phi_1 = \frac{1}{2}Log(\frac{3\pm\sqrt{5}}{2})$. We will consider a domain wall solutions such that the scalar ϕ_1 interpolates between these two extrema. In order to find such a solution, we choose the following ansatz for the metric and the gauge field

$$ds^2 = e^{2A}(-hdt^2 + d\vec{x}_5^2) + \frac{dr^2}{h}, \qquad A^{(1)} = B_1 dt. \tag{2.5}$$

With this ansatz, the equations of motion turn out to be

$$\begin{aligned} -5A'' &= 2\frac{e^{-2A}}{h^2}g^2\sinh^2 2\phi_1 B_1^2 + 2\phi_1'^2,\\ h'' + 6A'h' &= 4\frac{e^{-2A}}{h}g^2\sinh^2 2\phi_1 B_1^2 + 4e^{-2A}B_1'^2,\\ 4h[\phi_1'' + (6A' + \frac{h'}{h})\phi_1'] &= -4\frac{e^{-2A}}{h}\sinh 4\phi_1 g^2 B_1^2 + \frac{m^2}{2}\frac{\partial V}{\partial\phi_1},\end{aligned}$$