Holographic superconductor developed in BTZ black hole background with backreaction

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Abstract: We develop a holographic superconductor in the BTZ black hole background with backreaction. We investigate the influence of the backreaction on the condensation of the scalar hair and dynamics of perturbation in the background spacetime. When the Breitenlohner-Freedman bound is approached,we argue that only one of two possible operators can reflect the real property of the condensation in the holographic superconductor. This argument is supported from the investigation in dynamics.

Model: The general action describing a charged, complex scalar field into the dimensional Einstein-Maxwell action with negative cosmological constant reads

$$S=\frac{1}{2\kappa^2}\int d^3x\sqrt{-g}(R+\frac{2}{l^2})+\int d^3x\sqrt{-g}\left[-\frac{1}{4}F^{ab}F_{ab}-|\nabla\psi-iqA\psi|^2-m^2|\psi|^2\right],$$

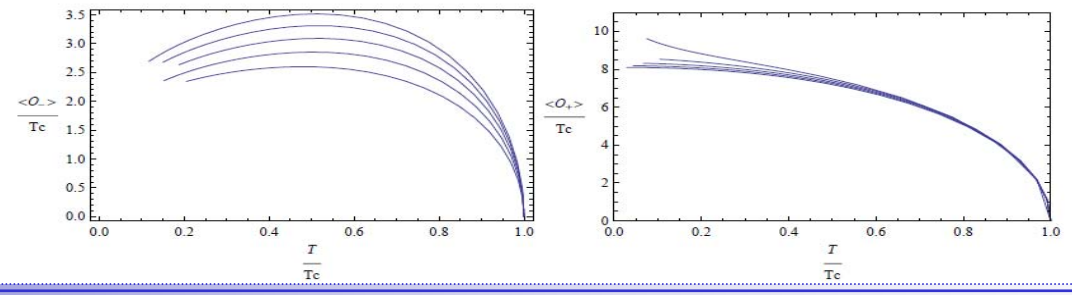
Combined with an ansatz of metric, one can deduced equations of motion from the above action:

$$\begin{aligned}
0 &= \psi''(r)+\psi'(r)\left[\frac{1}{r}+\frac{f'(r)}{f(r)}-\frac{\chi'(r)}{2}\right]+\psi(r)\left[\frac{q^2\phi(r)^2e^{\chi(r)}}{f(r)^2}-\frac{m^2}{f(r)}\right],\\
0 &= \phi''(r)+\phi'(r)\left[\frac{1}{r}+\frac{\chi'(r)}{2}\right]-\frac{2q^2\phi(r)\psi(r)^2}{f(r)},\\
0 &= f'(r)+2\kappa^2 r\left[\frac{q^2\phi(r)^2\psi(r)^2e^{\chi(r)}}{f(r)}+f(r)\psi'(r)^2+m^2\psi(r)^2+\frac{1}{2}e^{\chi(r)}\phi'(r)^2\right]-\frac{2r}{l^2},\\
0 &= \chi'(r)+4\kappa^2 r\left[\frac{q^2\phi(r)^2\psi(r)^2e^{\chi(r)}}{f(r)^2}+\psi'(r)^2\right],
\end{aligned}$$

At the spatial infinity, the asymptotic behaviors of the solutions are

$$\chi\to 0\ ,\quad f(r)\sim\frac{r^2}{l^2}\ ,$$
$$\phi(r)\sim\rho+\mu\ln(r)\ ,\quad \psi(r)\sim\frac{\psi_-}{r^{\lambda_-}}+\frac{\psi_+}{r^{\lambda_+}},$$

Numerically solving the equation under the boundary conditions at the horizon and AdS boundary. Form some appropriate parameters either ψ_+ or ψ_- can be chose dual to the scalar operator in the field theory to describe the condensate.



Plot of the condensate as a function of temperature for m^2 = −1 with ψ_+ = 0 (the left panel) and ψ_- = 0 (the right panel), respectively. In the left panel five lines from bottom to top correspond to κ^2 = 0 , 0.05 , 0.1 , 0.15 , 0.2 respectively, but they are arranged the other way around in the right panel.

Conclusions: We developed the holographic superconductors in the BTZ black hole background with backreactions. From the critical temperature and the dynamical perturbation properties, we observed that the stronger backreaction makes it more difficult for the scalar hair to condensate. In the holographic superconductor, we have two operators to describe the condensation. It is of interest to ask which one can really reflect the properties of the condensation. In the constructed (1+1)-dimensional holographic superconductor, we observed that the condensation read from expectation values of different operators reflects different influence of the backreaction on the formation of the scalar hair. This phenomenon was also observed in the study of the effect of the backreaction in the (2+1)-dimensional holographic superconductor.

Main References: [1] K. Maeda, M. Natsuume and T. Okamura. Phys. Rev. D 79, 126004 (2009).
[2] Q.Y. Pan, B. Wang, E. Papantonopoulos, J. Oliveria, and A.B. Pavan, Phys. Rev. D 81, 106007 (2010).
[3] S. A. Hartnoll, C. P. Herzog and G. T. Horowitz, Phys. Rev. Lett. 101, 031601 (2008).
[4] S. S. Gubser, Phys. Rev. D 78 (2008) 065034.
[5] S. A. Hartnoll, C. P. Herzog, and G. T. Horowitz, JHEP 0812 (2008) 015.