Towards generalising holographic superconductors

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Introduction

As one of the most compelling results emerging from string theory, the **AdS/CFT correspondence** has awaken a considerable amount of interest of late. In its first formulation by Maldacena [1], this principle established a relation between a string theory on asymptotically Anti-de-Sitter (AdS) spacetime and a strongly-coupled conformal field theory (CFT) on its boundary. However, its possibilities reach much further afield.

It is in the context of condensed matter physics that many recent developments have occurred. In particular, holographic techniques have been used to successfully describe the **second order phase transition in superconductors**. Namely, accurate descriptions of the temperature dependence of the condensate and conductivity of s- [2], p- [3] and d-wave [4] superconductors have been realised, opening the possibility of theoretically characterizing **unconventional superconductors** — that is, those which do not comply with the widely-known BCS theory.

Holographic superconductors

- Holographic superconductivity is realised by enforcing a matter field —let it be the rank ℓ tensor $\boldsymbol{B}_{\nu_1,\ldots\nu_\ell}$ in Eq. (2)— to condense about an AdS black hole (BH)'s horizon at temperature T.
- So as to counteract gravity, said matter field is endowed with a charge q under some EM-like $U(1)$ symmetry.
- The interplay between the attractive force of the BH and the EM repulsion mimics the critical behaviour:
  - If $T < T_c$, a condensate emerges over the BH's horizon.
  - If $T > T_c$, the condensate falls into the BH.
- However, **the AdS BH metric is only a gravity-motivated choice.**
- From a calculational point of view, it might be interesting to work with a more general metric.
- At sight of how alike they are, we would also like to tackle all models at once. This motivates the choice of the **generalised model** on the right.
- We have made use of the simple **semi-analytical method** introduced in Ref. [5] to study the condensate in the general case. This method involves:
  - Calculating asymptotic solutions of the equations of motion (EOMs) of the theory at the asymptotic regiona and near the BH's horizon.
  - Finding suitable boundary conditions.
  - Matching the solutions at a intermediate point.

The generalised model

We have generalised the approach, both at the level of the metric and the action:

- Our generalized metric retains an horizon-like singularity at $r = r_H$,

$$ds^2 = -f(r)dt^2 + \frac{dr^2}{f(r)} + r^2(dx^2+dy^2); \qquad f(r) = h(r)\left(1 - \frac{r_H}{r}\right). \tag{1}$$

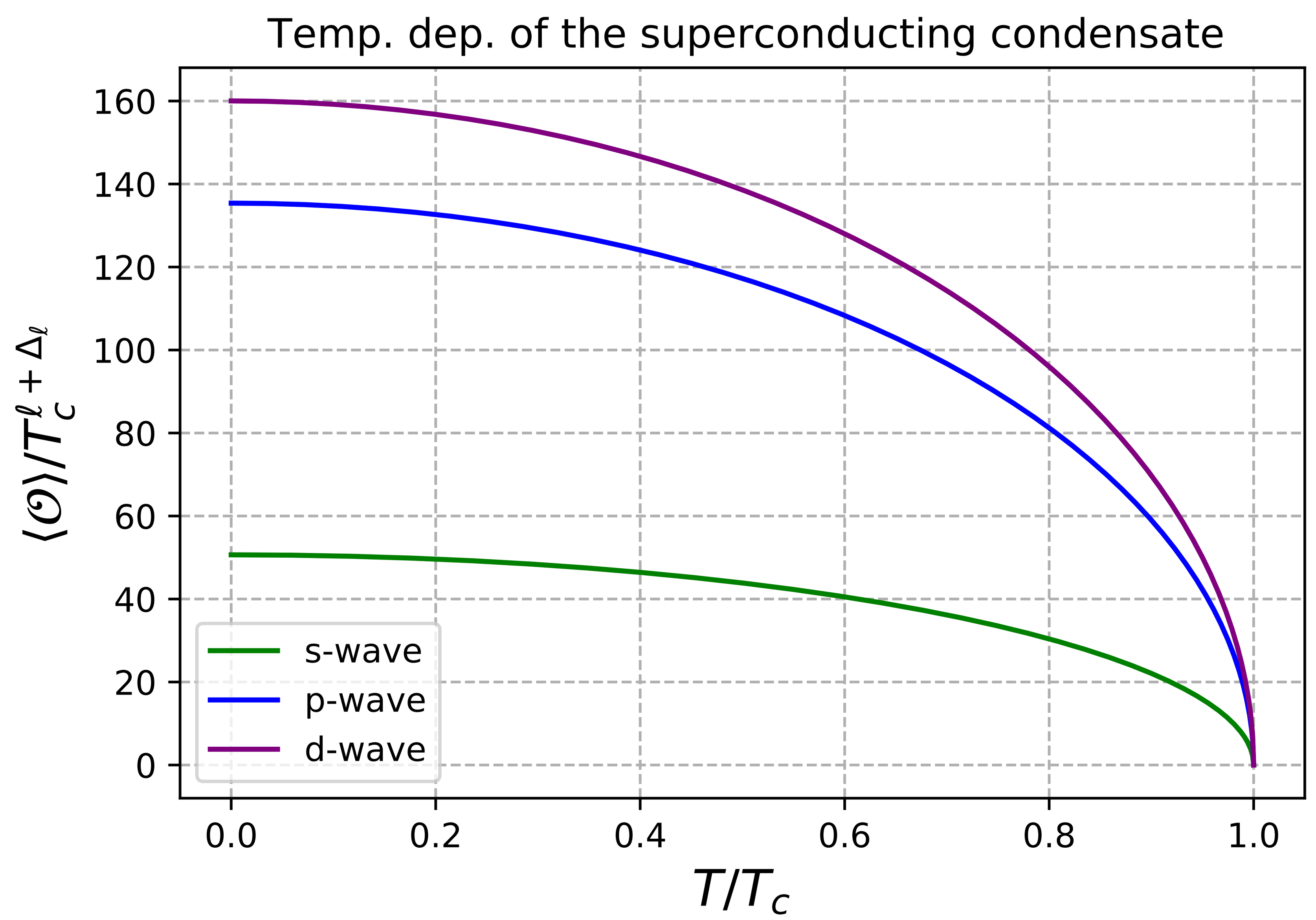
- Meanwhile, the generalized action reads

$$S = \frac{1}{2\kappa^2}\int d^4x\sqrt{-g}\left(\mathcal{R} + \frac{6}{L^2} + \mathcal{L}_m + \mathcal{L}_a\right), \tag{2}$$

  where the minimal contributions to the Lagrangian is

$$\mathcal{L}_m = -\left[\frac{1}{4}F_{\mu\nu}F^{\mu\nu} + |\mathcal{D}_\mu \boldsymbol{B}_{\nu_1,\ldots,\nu_\ell}|^2 + m^2|\boldsymbol{B}|^2\right], \tag{3}$$

- For higher spin matter fields ($\ell \geq 1$), suitable constraints must accompany this action to eliminate non-physicalities.



Results & prospects

- Our model yields the correct equations of motion (EOMs) for the s-, p- and d-wave cases, module a number of qualitatively irrelevant terms.
- Said terms can potentially be removed from the EOMs by imposing the appropriate dynamical constraints (ongoing work).
- Our semi-analytical approach gives rise to a condensate

$$\langle\mathcal{O}\rangle \sim \sqrt{1 - \frac{T}{T_c}} \tag{4}$$

  as it can be observed in the Figure. The results are in agreement with the numerical calculations to a reasonable degree.
- The model could be used as a first step towards the construction of holographic superconductors with a more complicated geometry (e.g. f-wave).
- A well-performing semi-analytical approach to calculate the **conductivity** is still being looked for.

References

[1] J. M. Maldacena, "The Large N limit of superconformal field theories and supergravity," *Adv. Theor. Math. Phys.* **2** (1998) 231–252, `arXiv:hep-th/9711200`.

[2] S. A. Hartnoll, C. P. Herzog, and G. T. Horowitz, "Building a Holographic Superconductor," *Phys. Rev. Lett.* **101** (2008) 031601, `arXiv:0803.3295 [hep-th]`.

[3] S. S. Gubser and S. S. Pufu, "The Gravity dual of a p-wave superconductor," *JHEP* **11** (2008) 033, `arXiv:0805.2960 [hep-th]`.

[4] F. Benini, C. P. Herzog, R. Rahman, and A. Yarom, "Gauge gravity duality for d-wave superconductors: prospects and challenges," *JHEP* **11** (2010) 137, `arXiv:1007.1981 [hep-th]`.

[5] R. Gregory, S. Kanno, and J. Soda, "Holographic Superconductors with Higher Curvature Corrections," *JHEP* **10** (2009) 010, `arXiv:0907.3203 [hep-th]`.

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