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Erratum: Nearly critical holographic superfluids

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We provide a correction to the results presented below equation (5.2) in section 5.1 of [1]. The main technical result affected by our correction concerns the dispersion relation of the quasi-normal modes related to fluctuations of the bulk complex scalar field ψ around normal phase black holes. According to the revised version of our results, the dispersion relations of our hydrodynamic quasi-normal modes are continuous across the superfluid phase transition.

The above correction leads us to advise the reader of the following.

- In the abstract, replace the sentences,

  > "We carry out an analysis of the corresponding modes and argue that at finite density the dispersion relations are discontinuous between the normal and the broken phase. We compare and contrast our results with earlier numerical work."

  with the single sentence,

  > "We carry out an analysis of the corresponding modes which allows us to compare and contrast our results with earlier numerical work."

- On page 2 of the introduction, omit the sentences,

  > "Naively, one might expect that when holding the wavelength fixed, in the limit of small gap the modes should match with the ones of the normal phase. However, we show that this is true only at zero background chemical potential."

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- On the same page, omit the sentence,

> "As we will see, the discontinuity mentioned above is related to the fact that the modes of oscillation of the order parameter are different between the normal and the broken phase. In the normal phase we have two copies of the same mode coming from its real and imaginary parts."

- Below equation (5.18), replace the sentences,

> "Using the matching of equation (4.16), and the definitions (4.13) we see that this pair of modes matches the modes of oscillation of the order parameter in the normal phase (5.6), only at zero chemical potential."

with,

> "Using the matching of equation (4.16), and the definitions (4.13) we see that this pair of modes matches the modes of oscillation of the order parameter in the normal phase (5.6)."

- In section 7, omit the phrase,

> "we have revealed interesting discontinuities in their dispersion relations"

Revised results of section 5.1

The analysis concerning the quasi-normal modes of the complex scalar ψ in section 5.1, is based on the polar decomposition $\psi = \rho\, e^{iq_r\theta}$. However, in the normal phase the background value of the complex scalar is trivial. This makes the fluctuations of the angular field $\delta\theta$ ill defined. As a result, the analysis presented in [1] is invalid in the case of background geometries at finite chemical potential.

The correct choice of variables to work with is fluctuactions of the form

$$\delta\psi_H(t,x;r) = e^{-i\,\omega\varepsilon^2(t+S)+i\varepsilon kx}\left(\alpha\,\delta\rho_{(0)}(r) + \varepsilon^2\,\delta\psi_{(2)}(r) + \cdots\right)\,, \tag{1}$$

with $a \in \mathbb{C}$ and $\delta\rho_{(0)}$ representing the static, source free solution that exists at the critical point. Given the Lagrangian of equations (2.1), the symplectic current for the perturbations of the gauge field A_α, the complex scalar ψ and the neutral scalar ϕ is,

$$\begin{aligned}\mathcal{P}^{\mu}_{\delta_1,\delta_2} = \delta_1 A_\alpha\,\delta_2\left(\frac{\partial\mathcal{L}}{\partial(\partial_\mu A_\alpha)}\right) + \delta_1\left(\frac{\partial\mathcal{L}}{\partial(\partial_\mu\psi)}\right)\delta_2\psi + \delta_1\left(\frac{\partial\mathcal{L}}{\partial(\partial_\mu\psi^\star)}\right)\delta_2\psi^\star \\ + \delta_1\phi\,\delta_2\left(\frac{\partial\mathcal{L}}{\partial(\partial_\mu\phi)}\right) - (1\leftrightarrow 2)\,.\end{aligned} \tag{2}$$

For the perturbations we are interested in, it is only the terms that involve variations of the complex scalar that will be relevant to our argument. This is due to the fact that, in the normal phase, the fluctuations of the complex scalar decouple from the gauge field and the neutral scalar.

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Following the strategy outlined in section (3.3) of [1] for $\delta\psi_2 = \delta\psi_H$ and $\delta\psi_1 = c\,\delta\rho_{(0)}$ with c complex, we obtain two distinct modes with dispersion relations,

$$\omega_1 = -i\,\frac{\int_0^\infty dr\,\delta\rho_{(0)}^2}{I}\,k^2\,,\qquad \omega_2 = -i\,\frac{\int_0^\infty dr\,\delta\rho_{(0)}^2}{I^*}\,k^2\,, \tag{3}$$

with $I = e^{2g^{(0)}}\left(\delta\rho^{(0)}_{(0)}\right)^2 + 2i\,q\,\int_0^\infty dr\,\frac{e^{2g}}{U}a_c\,\delta\rho_{(0)}^2$. After using the equation of motion of the gauge field in the broken phase, the above dispersion relations can also be written as,

$$\omega_1 = -i\,w_0\,\bar{\Gamma}_0\,k^2\,,\qquad \omega_2 = -\omega_1^* = -i\,w_0\,\Gamma_0\,k^2\,, \tag{4}$$

in the notation of [1] matching the expressions of equations (5.18).

Acknowledgments

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References

[1] A. Donos and P. Kailidis, *Nearly critical holographic superfluids*, *JHEP* **12** (2022) 028 [arXiv:2210.06513].