通过 quench 实现标量化带电 AdS 黑洞的去标量化

Descalarization by Quenching Charged Hairy Black Hole in asymptotically AdS spacetime

arXiv:2210.14539

中国科学院大学

2023 年 4 月 23 日

研究动机

- RN-AdS 黑洞对复标量扰动的两种不稳定性机制
  - near-horizon 不稳定性 [arXiv:1612.03172]
  - 超辐射不稳定性 [arXiv:1512.05358]
- 去标量化的机制
  - 双黑洞并合 [arXiv:2012.10436]
  - 黑洞吸积 [arXiv:2203.03672]
- 发现了一种新的去标量化的机制：quench

Einstein-Maxwell-scalar 模型

- 4 维 AdS 时空中的 Einstein-Maxwell-scalar 模型

$$\mathcal{L} = R - 2\Lambda - \frac{1}{4}F_{\mu\nu}F^{\mu\nu} - D_\mu\psi(D^\mu\psi)^* - m^2|\psi|^2$$

其中 $D_\mu = \nabla_\mu - iqA_\mu$

- 在边界附近标量场有两支渐近解

$$\psi \sim \psi_1 r^{-(3-\Delta)} + \psi_2 r^{-\Delta}, \quad r \to \infty$$

$$\Delta(\Delta - 3) = m^2 L^2$$

- ψ_1: source, ψ_2: response
- BF-bound: $-9/4 \le m^2 L^2 \le 0$

对复标量扰动的不稳定性

- near-horizon 不稳定性（极端情况下）

$$4q^2L^2 \geq \left[m^2L^2 + \frac{3}{2} + \frac{1}{4}(r_+/L)^{-2}\right]\left[\frac{6+(r_+/L)^{-2}}{3+(r_+/L)^{-2}}\right]$$

  - 当 $r_+/L \to \infty$

$$4q^2L^2 \geq 2(m^2L^2 + \frac{3}{2}) + O((r_+/L)^{-2})$$

  - 当 $r_+/L \to 0$

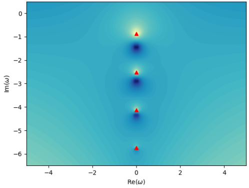
$$4q^2L^2 \geq \frac{1}{4}(r_+/L)^{-2} + O(1)$$

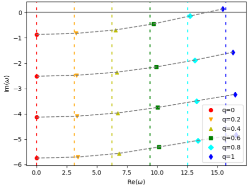
- 超辐射不稳定性

$$0 \leq \mathrm{Re}(\omega) \leq \frac{qQ}{r_+}$$

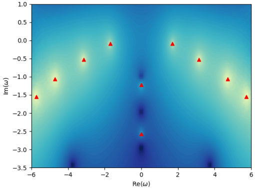
QNM

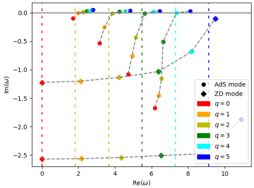
大黑洞：


Im(ω)
Re(ω)


Im(ω)
Re(ω)
q=0
q=0.2
q=0.4
q=0.6
q=0.8
q=1

小黑洞：


Im(ω)
Re(ω)


Im(ω)
Re(ω)
AdS mode
ZD mode
q = 0
q = 1
q = 2
q = 3
q = 4
q = 5

Ward-Takahashi 恒等式

$$2\kappa_4^2 S_{\text{ren}} = \int_M dx^4 \sqrt{-g}\mathcal{L} + 2\int_{\partial M} dx^3 \sqrt{-\gamma} K$$
$$- \int_{\partial M} dx^3 \sqrt{-\gamma}(4 + R[\gamma] + |\psi|^2)$$

$$\langle O \rangle = \kappa_4^2 \lim_{r\to\infty} \frac{r^2}{\sqrt{\gamma}} \frac{\delta S_{\text{ren}}}{\delta \psi} = -\frac{1}{2} \lim_{r\to\infty} r^2 [\psi^* + n^\mu (D_\mu \psi)^*]$$

$$\Downarrow$$

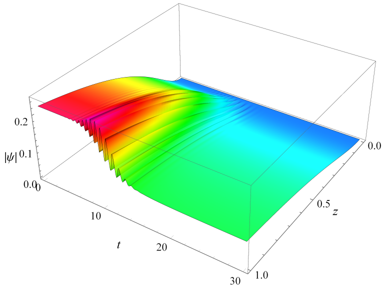
$$\partial_t Q = 2iq(\psi_1 \langle O \rangle - \psi_1^* \langle O \rangle^*)$$

$$\partial_t \langle T_{tt} \rangle = -\langle O \rangle D_t \psi_1 - \langle O \rangle^* (D_t \psi_1)^*$$

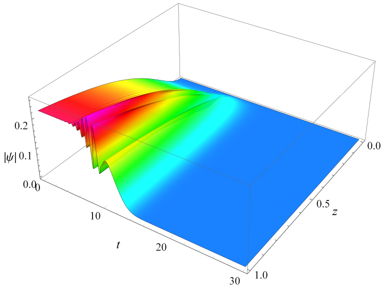
去标量化

quench:

$$\psi_1 = H\exp\left[-\frac{(t-10)^2}{6}\right]$$

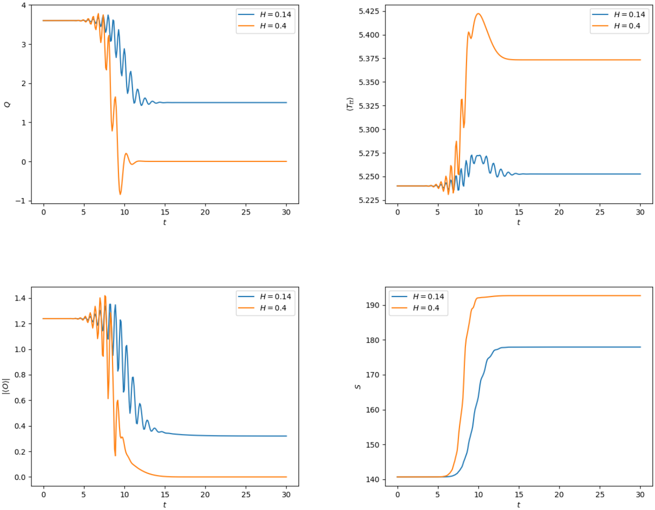


(a) $H = 0.14$

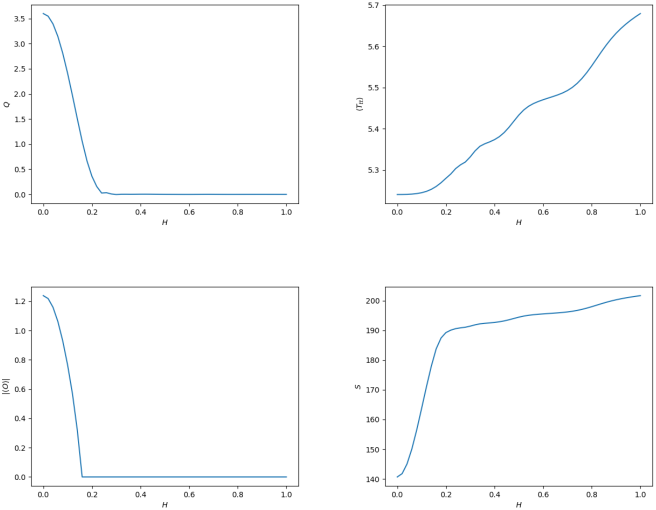


(b) $H = 0.4$

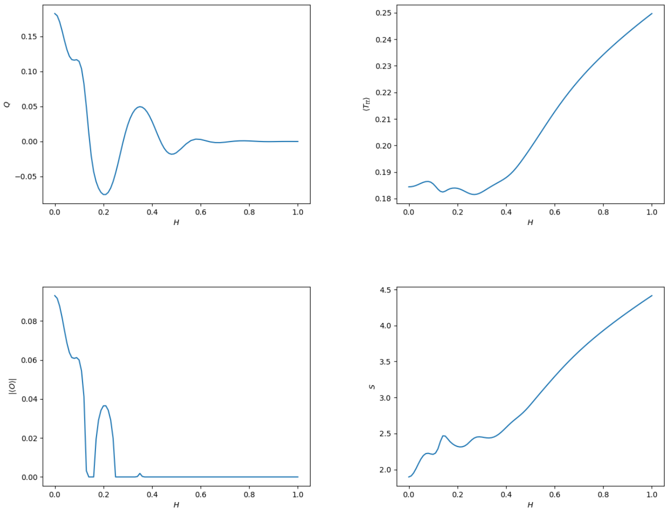
去标量化



quench 强度的影响：大黑洞



quench 强度的影响：小黑洞



谢谢！

附录：演化方案

[arXiv:1309.1439]

$$ds^2 = -2W(t,r)dt^2 + 2dtdr + \Sigma(t,r)^2 d\Omega_2^2$$

Einstein equations:

$$0 = \Sigma'' + \frac{1}{2}|\psi'|^2\Sigma,$$

$$0 = (\Sigma d_+\Sigma)' - \frac{1}{2}\left(3 - \frac{1}{4}A'^2 + |\psi|^2\right)\Sigma^2 - \frac{1}{2},$$

$$0 = W'' + \frac{2(d_+\Sigma)'}{\Sigma} - 3 - \frac{1}{4}A'^2 - |\psi|^2 + \mathrm{Re}\left[(d_+\psi - iqA\psi)(\psi')^*\right],$$

$$0 = d_+d_+\Sigma - W'd_+\Sigma + \frac{1}{2}|d_+\psi - iqA\psi|^2\Sigma,$$

Maxwell equations:

$$0 = A'' + 2A'\frac{\Sigma'}{\Sigma} - 2q\mathrm{Im}\left[\psi^*\psi'\right],$$

$$0 = d_+A' + 2A'\frac{d_+\Sigma}{\Sigma} + 2q\mathrm{Im}\left[\psi^*(d_+\psi - iqA\psi)\right]$$

Scalar equation:

$$0 = \left[\Sigma(d_+\psi - iqA\psi)\right]' + \psi' d_+\Sigma + \frac{1}{2}iqA'\Sigma\psi + \Sigma\psi,$$