Double Phase Transitions of Kerr-AdS Black Hole

Yu Dai Tsai

NTHU PHYS

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The Black Hole Thermodynamics

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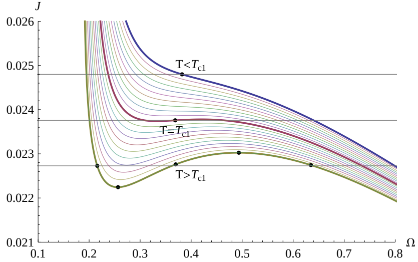

Figure: The critical isotherms near the critical temperature T_{c1}.

The Kerr-AdS metric

$$ds^2 = -\frac{\Delta_r}{\Sigma}\left(dt - \frac{a\sin^2\theta}{\Xi}d\phi\right)^2 + \frac{\Sigma}{\Delta_r}dr^2 + \frac{\Sigma}{\Delta_\theta}d\theta^2 + \frac{\Delta_\theta \sin^2\theta}{\Sigma}\left(adt - \frac{r^2+a^2}{\Xi}d\phi\right)^2 \quad (1)$$

where

$$\Delta_r = (r^2+a^2)\left(1+\frac{r^2}{l^2}\right) - 2Mr, \quad \Xi = 1 - \frac{a^2}{l^2},$$

$$\Delta_\theta = 1 - \frac{a^2}{l^2}\cos^2\theta, \qquad \Sigma = r^2 + a^2\cos^2\theta. \; (2)$$

The Kerr-AdS Thermodynamic quantities

Gibbons et al. in arXiv:hep-th/0408217v3 (2006)
The "physical" mass (or energy) E and angular momentum J is defined as

$$E = \frac{M}{\Xi^2}, \quad J = \frac{Ma}{\Xi^2}. \tag{3}$$

The Hawking temperature and the entropy $T = \frac{\kappa}{2\pi}$ and $S = \frac{A}{4}$. The angular velocity of horizon Ω,

$$\Omega = -\frac{g_{t\phi}}{g_{\phi\phi}} = \frac{a\Xi[(r^2 + a^2)\Delta_\theta - \Delta_r]}{\Gamma}, \ \Delta_r \to 0, \tag{4}$$

where $\Gamma = (r^2 + a^2)^2 \Delta_\theta - \Delta_r a^2 \sin^2 \theta$.

the first law of the black hole thermodynamics

The relation between each quantity gives us the first law of the black hole thermodynamics, which is

$$dE = TdS + \Omega\delta J \ . \tag{5}$$

a: attraction between each particle, b: the volume of the particle

$$(p + \frac{n^2 a}{V^2})(V - nb) = nRT$$

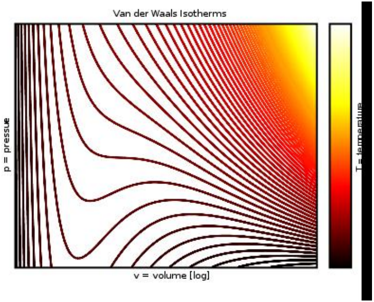

Figure: The critical isotherms near the critical temperature T_{c1}.

The Kerr-AdS black hole

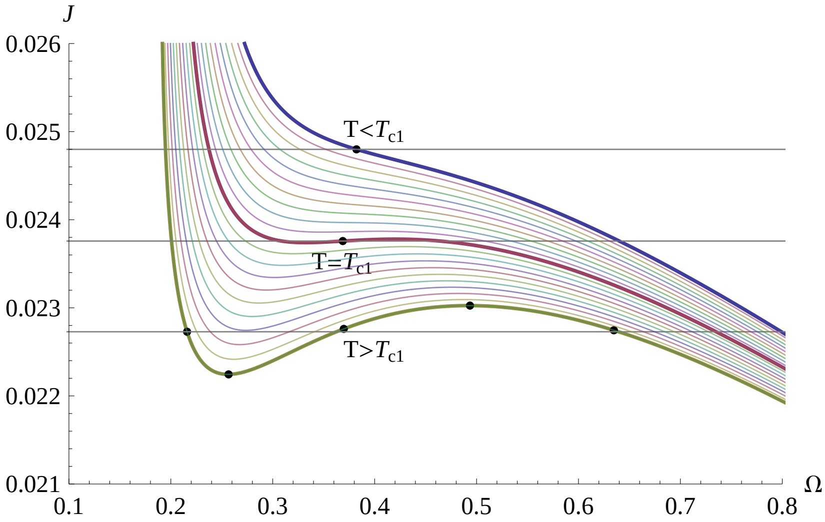

Figure: The critical isotherms near the critical temperature T_{c1}.

critical isotherm:

$$\Omega - \Omega_c = A_\delta |J - J_c|^\delta sign(J - J_c), \quad (T = T_c). \tag{6}$$

order parameter:

$$\eta_1 = -A_\beta (T - T_c)^\beta, \quad (T > T_c). \tag{7}$$

heat capacity

$$C_J = \begin{cases} A_{\alpha'} \{-(T - T_c)\}^{-\alpha'}, & (T < T_c) \\ A_{\alpha'} \{+(T - T_c)\}^{-\alpha}, & (T < T_c) \end{cases} . \tag{8}$$

isothermal compressibility

$$\kappa_T = \begin{cases} A_{\gamma'} \{-(T - T_c)\}^{-\gamma'}, & (T < T_c) \\ A_\gamma \{+(T - T_c)\}^{-\gamma}, & (T > T_c) \end{cases} . \tag{9}$$

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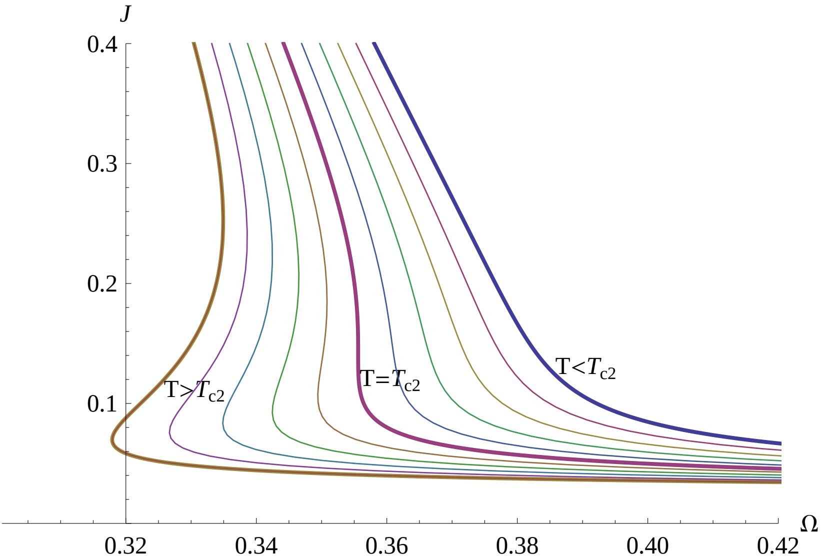
the second second order phase transition



The free energy F near the critical point:

$$F_s(\epsilon, \omega) = c_\epsilon \epsilon^2 + c_\omega \omega^{4/3}.$$

Thus we have the scaling symmetry of the free energy near the critical point,

$$F_s(\Lambda^{1/2}\epsilon, \Lambda^{3/4}\omega) = \Lambda F_s(\epsilon, \omega),$$

with all the scaling symmetry follows.

Write the critical exponents in terms of p and q as

$$\alpha = \frac{2p-1}{p}, \quad \beta = \frac{1-q}{p}, \quad \gamma = \frac{2q-1}{p}, \quad \delta = \frac{q}{1-q}. \tag{10}$$

From the equations above, the critical exponents satisfy the following relations,

$$\begin{aligned}
&\alpha + 2\beta + \gamma = 2 \ , \\
&\alpha + \beta(\delta + 1) = 2 \ , \\
&\gamma(\delta + 1) = (2 - \alpha)(\delta - 1) \ , \\
&\gamma = \beta(\delta - 1).
\end{aligned} \tag{11}$$

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Results and Discussion

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- Mean field gravity?

- Hortnoll (hep-th/0803.3295): Building a Holographic Superconductor

The rotating holographic superconductor

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- jobs for string theorists