Unruh effect and Holography

Takayuki HIRAYAMA
@NCTS & NTNU, Taiwan

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Based on a collaboration with
Peggy Kao, Shoichi Kawamoto, Feng-Li Lin
(NTNU, Taiwan)

Unruh effect

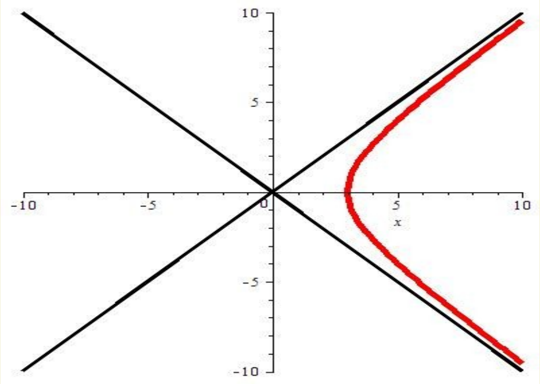
- uniformly accelerated observers (Rindler observers) in Minkowski space see a thermal radiation with $T=\frac{a}{2\pi}$.

['76 Unruh]

- Minkowski flame $|0_M\rangle$

$$ds^2=-dt^2+dx^2 \qquad a_\omega|0_M\rangle=0$$

$$\phi(x)\sim a_\omega^\dagger e^{i\omega t-kx}+h.c.$$



- Rindler observer $x^2-t^2=b^2,\ \ b^2=1/a^2$

$$t=b\,e^{\xi/b}\sinh\tau/b \qquad x=b\,e^{\xi/b}\cosh\tau/b$$

$$\rightarrow\ \xi=0$$

- Comoving flame (Rindler space)

$$ds^2=e^{2\xi/b}(-d\tau^2+d\xi^2)$$

$$\phi(x)\sim a_\omega^{R\dagger}e^{i(\omega\tau-k\xi)}+h.c. \qquad a_\omega^R|0_R\rangle=0$$

$$\langle 0_M|a_\omega^{R\,\dagger}a_\omega^R|0_M\rangle=\frac{1}{e^{2\pi\omega/a}-1}$$

Unruh effect

- The chiral symmetry breaking in QCD is restored for a uniformly accelerated observer with $a > a_c \; , a_c \sim \Lambda_{QCD}$.

- This is discussed by studying Nambu-Jona-Lasino model in Rindler space.

['04 Ohsaku]

- Now, in this talk, we discuss this phenomena from AdS dual by using AdS/CFT correspondence.

- Plan of talk :

  (1) Review of uniformly accelerated string in AdS space, and the comoving flame

  (2) Introduce probe D7 brane, and compute the chiral condensate

  (3) drag force

  (4) comments on future works

(Review) Uniformly accelerated string in AdS

['08 Xiao]

- Think about a observer on a particle (quark) with $x^2 - t^2 = b^2$ on the AdS boundary.

- A quark is the endpoint of open string, and then let us obtain a open string profile with the boundary condition $x^2 - t^2 = b^2$ on the AdS boundary, i.e. uniformly accelerated string in AdS.
- From Nambu-Goto action for a string, one obtains

$$x^2 - t^2 = b^2 - u^2$$

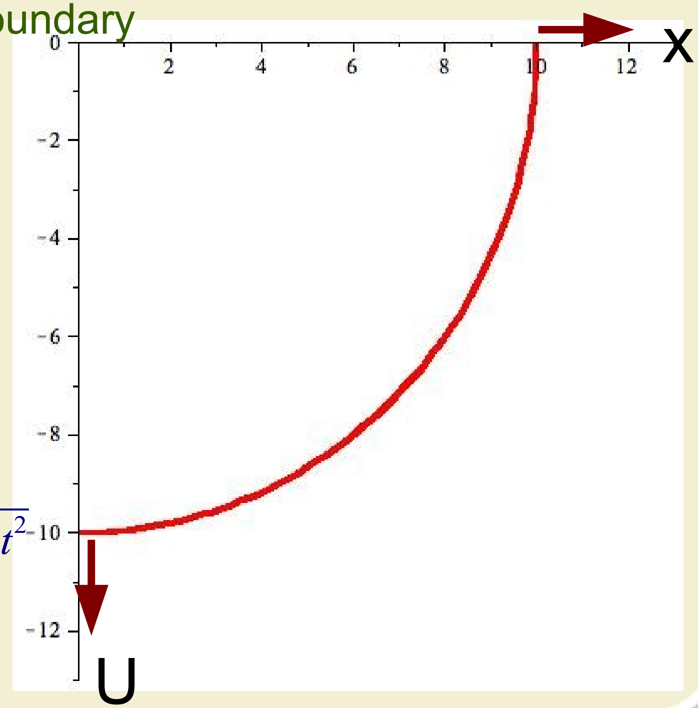
$$ds^2 = \frac{R^2}{u^2}(-dt^2 + dx^2 + dy^2 + dz^2 + du^2)$$

- Comoving flame

$$t = \sqrt{b^2 - r^2}\, e^{\xi/b} \sinh \tau/b$$

$$x = \sqrt{b^2 - r^2}\, e^{\xi/b} \cosh \tau/b$$

$$u = r\, e^{\xi/b} \qquad \rightarrow \quad \xi = 0$$



Review of accelerated string in AdS

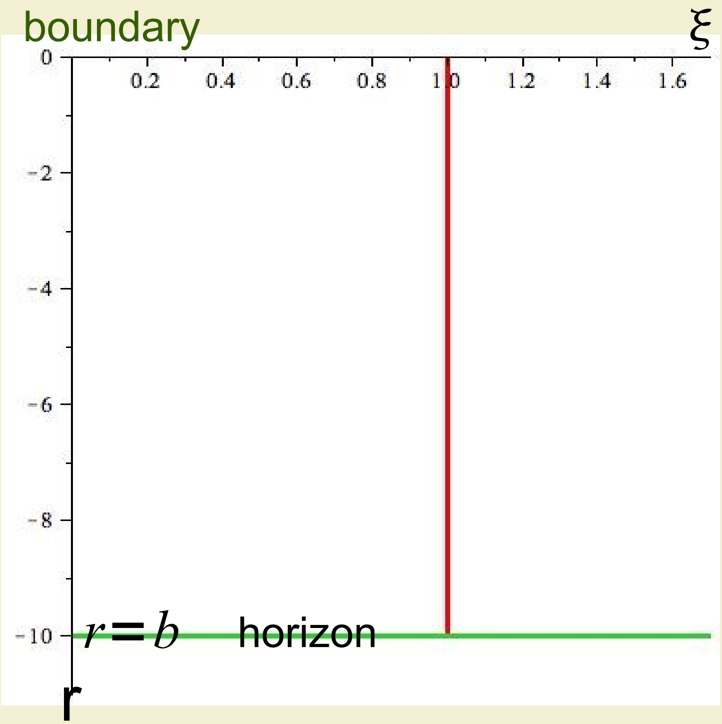
- Comoving flame ['08 Xiao]

$$ds^2=\frac{R^2}{r^2}\left[-h(r)d\tau^2+d\xi^2+e^{-2\xi/b}(dy^2+dz^2)+\frac{dr^2}{h(r)}\right], \quad h(r)=1-\frac{r^2}{b^2}$$

open string is static $\xi=0$.

Temperature is $T=\frac{a}{2\pi}$, $a=1/b$.

- This tells r is treated as the energy scale for accelerated obs. in CFT dual.



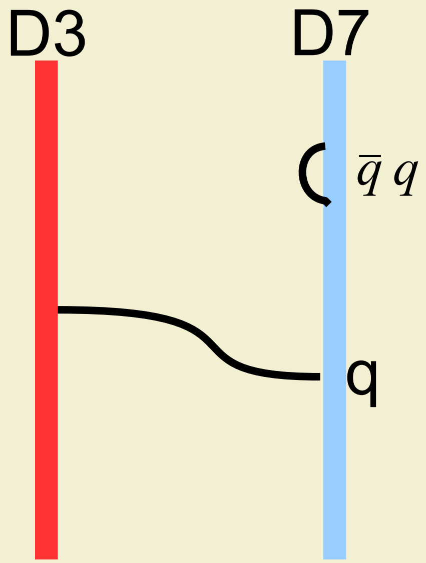
[H, Kao, Kawamoto, Lin]

- The stress energy tensor computed from this comoving flame, we obtain

$$T^{\mu}_{\nu}\propto(3,-1,-1,-1) \qquad p=\epsilon/3\propto N^2T^4$$

Probe D7 brane

- D7 brane introduces quark in the theory. The scalar field on D7 brane corresponds to the composite op. $O \sim \bar{q}\, q$.



- We can compute the chiral condensate by using GKP-Witten relation in AdS/CFT.

Probe D7 brane

[H, Kao, Kawamoto, Lin]

- We propose introducing D7 brane probe in the following way.

  Static in τ in the comoving flame $\qquad r^{-1} = b^{-1}\sqrt{u^{-2}(x^2 - t^2) + 1}$

  the scalar field on D7 brane which determines the shape of D7 brane depends on r and does not depend on τ, i.e.

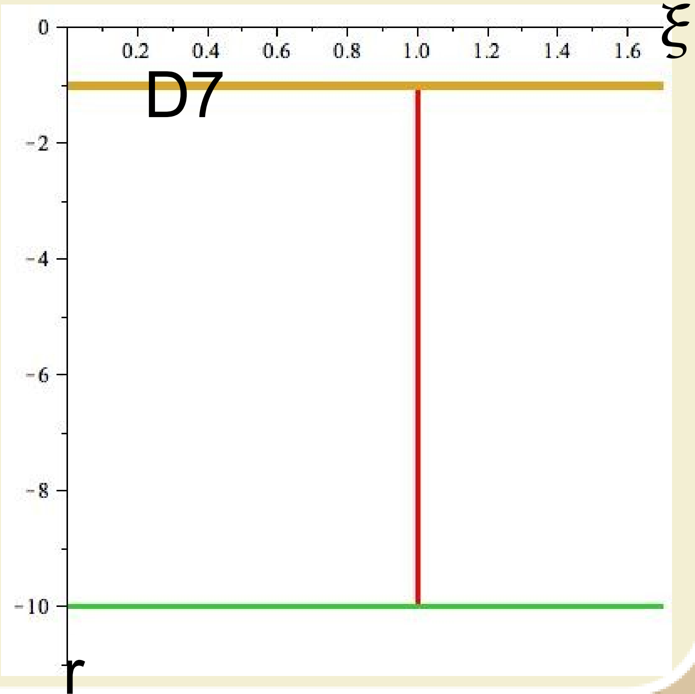
  $$\psi = \psi(r) \qquad \psi \leftrightarrow O^R \sim \bar{q}q$$

- We obtain the solution for $\psi(r)$ from DBI action for D7 brane in the comoving flame.

  $$\psi(r) = m(r + \cdots) + \nu(r^3 + \cdots)$$

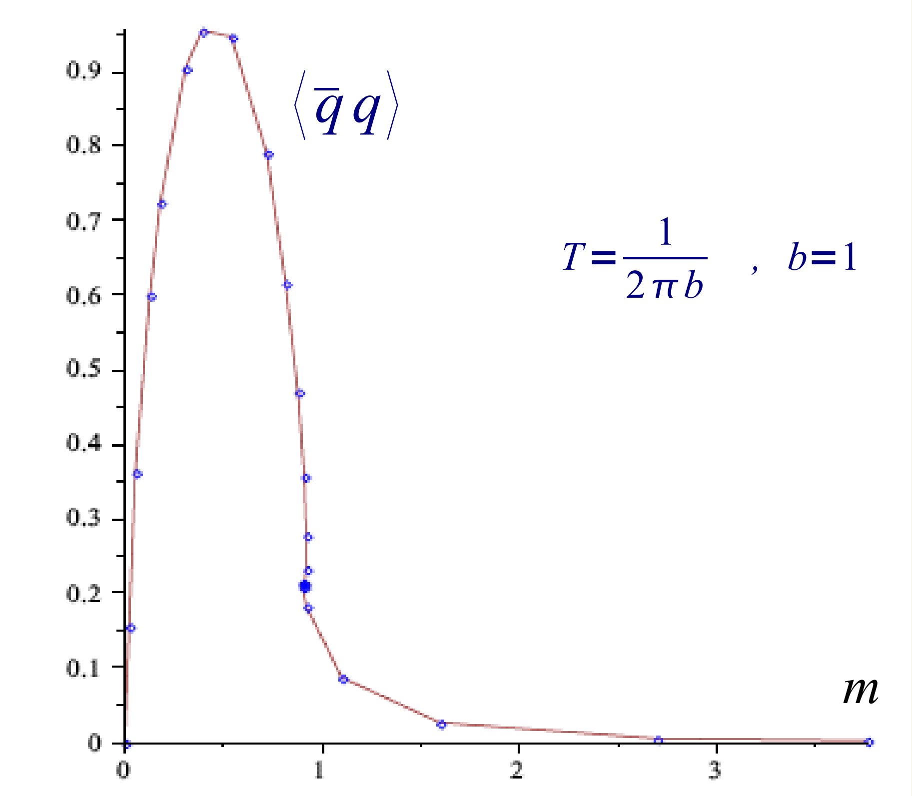
  Following GKP-Witten and the holographic renormalization, we can compute $\langle 0_M | O^R | 0_M \rangle$

$$\langle 0_M | O^M | 0_M \rangle = 0 \qquad O^M \sim \bar{q}q$$

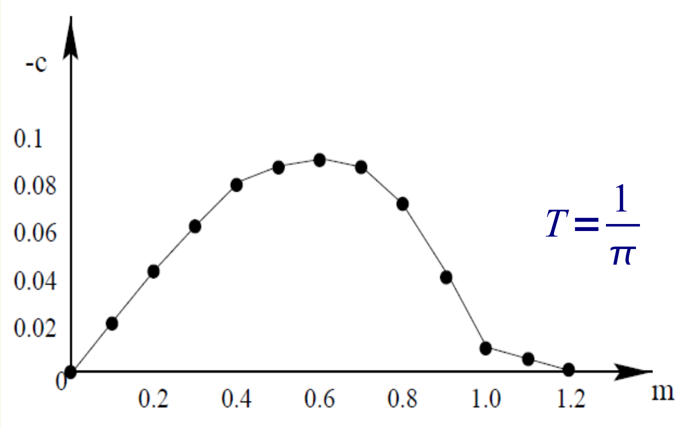


Probe D7 brane

- The chiral condensate which we obtain is :



- This behavior is similar to AdS-BH case.



Drag force

- We discuss a trailing string in the comoving flame, and compute the drag force. This gives another check to see if we can properly compute the finite temp. physics.

- Comoving flame

$$ds^2 = \frac{R^2}{r^2}\left[-h(r)\,d\tau^2 + d\xi^2 + e^{-2\xi/b}(dy^2 + dz^2) + \frac{dr^2}{h(r)} \right] , \quad h(r) = 1 - \frac{r^2}{b^2}$$

- A trailing string, i.e.

$$\xi(\tau, r) = v\tau + \xi(r)$$

We obtain $\xi(r)$ from Nambu-Goto action. Then we can compute

$$F_{drag} = \frac{dp}{dt} = \pi_\xi = \frac{\pi\sqrt{\lambda}\,T^2}{2}\frac{v}{1-v^2}$$

AdS BH $\quad F_{drag} = \frac{\pi\sqrt{\lambda}\,T^2}{2}\frac{v}{\sqrt{1-v^2}}$

Summary and future works

- We discuss Unruh effect from AdS dual picture, and propose how to introduce D7 brane. Then we computed the chiral condensate.
- We also computed the stress energy tensor, and the drag force. All the results are reasonable and pick up the temperature dependence.
- Thus our procedure collectly discuss Unruh effect from AdS side.
- This is another way to introduce temperature in AdS/CFT, and we can compute othrer thermodynamics, hydrodynamics quantities.

App : Stress energy tensor

- To show this picture is collect, we compute the stress energy tensor.

$$ds^2 = \frac{R^2}{r^2}\left[-\left(1-\frac{r^2}{b^2}\right)d\tau^2 + d\xi^2 + e^{-2\xi}(dy^2+dz^2) + \frac{dr^2}{1-\frac{r^2}{b^2}}\right]$$

$$S = \frac{-1}{16\pi G}\int d^5x\sqrt{g}(R-2\Lambda) - \frac{1}{8\pi G}\int d^{4x}\sqrt{\gamma}\,\Theta + \frac{1}{8\pi G}S_{c.t}(\gamma)$$

$$T^{\mu\nu} = \frac{2}{\sqrt{\gamma}}\frac{\delta S}{\delta\gamma_{\mu\nu}}$$

After canceling the divergences, we obtain

$$T^{\mu}_{\nu} \propto (3,-1,-1,-1) \qquad p = \epsilon/3$$

and Hawking temperature is obtained as

$$T = \frac{a}{2\pi} \quad , \quad a = 1/b$$