Shear viscosity of a highly excited string and black hole membrane paradigm

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Mysteries of black holes

- Microscopic origin of Bekenstein–Hawking entropy

\[ S_{BH} = \frac{A}{4G} \]

(A: area of the event horizon)

- Microscopic origin of membrane paradigm

“A certain fictitious viscous membrane seems to be sitting on a stretched horizon for a distant observer.”

\[ \eta_{BH} \quad \eta_{BH} = \frac{1}{16\pi G} \]

\[ s_{BH} = \frac{1}{4\pi} \]

We need a consistent quantum theory which includes gravity.

String theory!
A large gravitational redshift of a black hole explains the difference between $S$ and $S_{BH}$.

Consider a highly excited string on a stretched horizon of a Schwarzschild black hole.

Due to the redshift, the energy for an observer at the stretched horizon is not the same as the energy for an asymptotic observer.

$$E_{sh} \sim \frac{G^{\frac{1}{d-2}} M^{\frac{d-1}{d-2}}}{l_s}$$

$$S_{sh} \sim l_s E_{sh} \sim G^{\frac{1}{d-2}} M^{\frac{d-1}{d-2}} \sim S_{BH}$$
Membrane paradigm from the viewpoint of a fundamental string

Can we reproduce the viscosity of the fictitious membrane from a highly excited string?

What is the viscosity of the string?

This is due to the fact that the stress tensor of the polymer itself is added to the stress tensor of the solvent.

In polymer physics,
Shear viscosity of the longitudinally reduced string on the stretched horizon

\[ \eta_r = \sqrt{\frac{6}{d-1}} \frac{Ml_s}{2V_{d-1}} \]

On the stretched horizon, we have to replace

\[ M \rightarrow E_{sh} \sim \frac{r_H^{d-1}}{G l_s}, \quad V_{d-1} \rightarrow r_H^{d-1} \]

This is consistent with the membrane paradigm

\[ \eta_{BH} = \frac{1}{16\pi G} \]
Summary

• We have obtained the shear viscosity and $\frac{\eta}{s}$ of the highly excited string by using the Kubo’s formula.

• We have estimated the shear viscosity and $\frac{\eta}{s}$ of the string on the stretched horizon of the black hole.

• The results are consistent with the black hole membrane paradigm.