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)

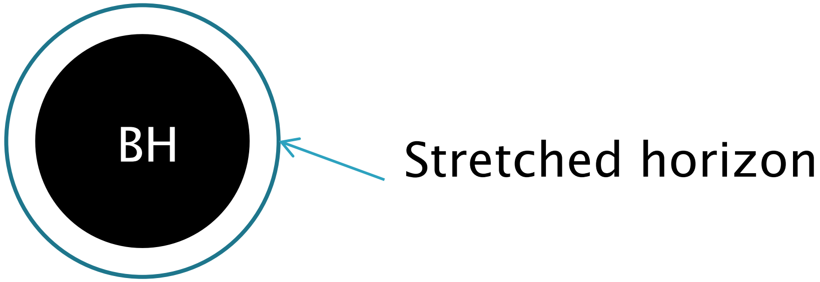
- Microscopic origin of membrane paradigm

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

Thorne, Price, Macdonald (1986)

$$\eta_{BH} = \frac{1}{16\pi G}$$

$$\frac{\eta_{BH}}{s_{BH}} = \frac{1}{4\pi}$$



We need a consistent quantum theory which includes gravity.

String theory!

Entropy of a macroscopic black hole from a fundamental string

Susskind (1993)

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

$$S \sim l_s M$$

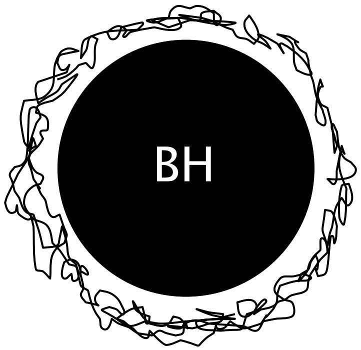
$$S_{BH} \sim G^{\frac{1}{d-2}} M^{\frac{d-1}{d-2}}$$

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

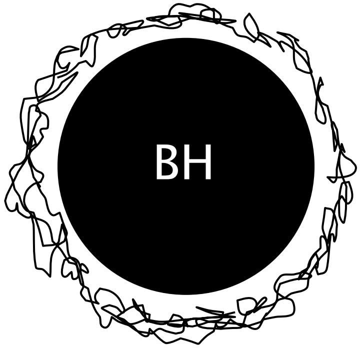
Due to the redshift, the energy for an observer at the stretched horizon is not the same as the energy for an asymptotic observer.

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

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



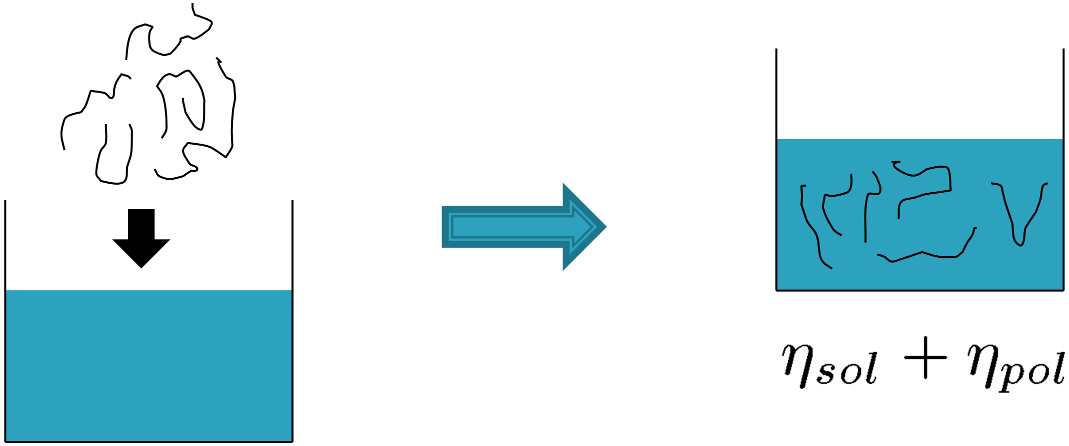
Membrane paradigm from the viewpoint of a fundamental string



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

What is the viscosity of the string?

In polymer physics,

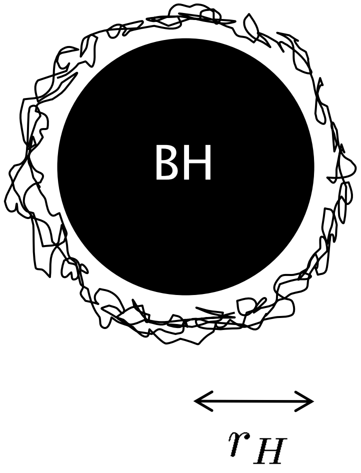


η_{sol}

$\eta_{sol} + \eta_{pol}$

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

Shear viscosity of the longitudinally reduced string on the stretched horizon



Shear viscosity of the longitudinally reduced string in the flat background

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

On the stretched horizon, we have to replace

$$M \to E_{sh} \sim \frac{r_H^{d-1}}{Gl_s} \quad , \qquad V_{d-1} \to r_H^{d-1}$$

$$\boxed{\eta_r^{sh} \sim \frac{E_{sh} l_s}{r_H^{d-1}} \sim \frac{1}{G}.}$$

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.