Drag force and jet quenching parameter in a strongly coupled anisotropic plasma from higher curvature gravity

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Introduction

- The **AdS/CFT correspondence** is a remarkable tool in the study of strongly coupled gauge theories which can be mapped to a dual, weakly coupled gravitational description. The quark gluon plasma produced in heavy ion collisions is an example of a strongly coupled system.
- **Anisotropy**: At early stages after the collision, the quark gluon plasma behaves as an anisotropic system due to expansion occuring mainly along the beam direction. In this work, we model the anisotropy in the dual gravity side using an external axion field linear in one of the spatial directions.
- **Gauss-Bonnet** gravity is a simple framework to study higher curvature effects. Higher curvature terms appear in string theory as stringy corrections to supergravity. In the gauge theory side, they correspond to finite 't Hooft coupling and finite N_c (rank of the gauge group) corrections. The Gauss-Bonnet term is given by

$$\mathcal{L}_{GB} = R^2 - 4R_{mn}R^{mn} + R_{mnrs}R^{mnrs}\,.$$

- In this work [1], our aim is to study the effects of the anisotropy and the Gauss-Bonnet term in some observables relevant to the study of the quark gluon plasma, namely, the drag force and the jet quenching parameter.

Gravity solution

- The action is given by five-dimensional gravity with negative cosmological constant coupled to an axion-dilaton system and the Gauss-Bonnet term

$$S = \frac{1}{16\pi G_5}\int d^5x\,\sqrt{-g}\left[R + 12 - \frac{1}{2}(\partial\phi)^2 - \frac{e^{2\phi}}{2}(\partial\chi)^2 + \frac{\lambda_{GB}}{2}\mathcal{L}_{GB}\right].$$

The scalar fields ϕ and χ are the dilaton and axion, respectively, and λ_{GB} is the Gauss-Bonnet coupling.
- An analytical solution can be obtained in the limit of small anisotropy,

$$ds^2 = \frac{1}{u^2}\left(-F(u)B(u)\,dt^2 + dx^2 + dy^2 + H(u)\,dz^2 + \frac{du^2}{F(u)}\right),$$
$$\chi = az, \quad \phi = \phi(u).$$

- Limit $a \to 0$: Gauss-Bonnet AdS black hole [2].
- Limit $\lambda_{GB} \to 0$: Anisotropic solution of Mateos and Trancanelli [3].
- Limit $a, \lambda_{GB} \to 0$: Gravity dual of $\mathcal{N} = 4$ Super Yang-Mills.

Drag force

- Consider an external heavy quark moving through the strongly coupled plasma with constant velocity v. Since the heavy quark loses energy due to the interaction with the plasma, a **drag force** F_{drag} is necessary to mantain the motion stationary.
- **Dual picture:** a classical string with an endpoint in the quark (at the boundary) and the other endpoint in the bulk, with the string trailing behind the quark [4, 5].

$$F_{drag}^{||} = e^{\phi/2}\frac{Hv}{u^2}\bigg|_{u=u_c}, \qquad F_{drag}^{\perp} = e^{\phi/2}\frac{v}{u^2}\bigg|_{u=u_c}.$$

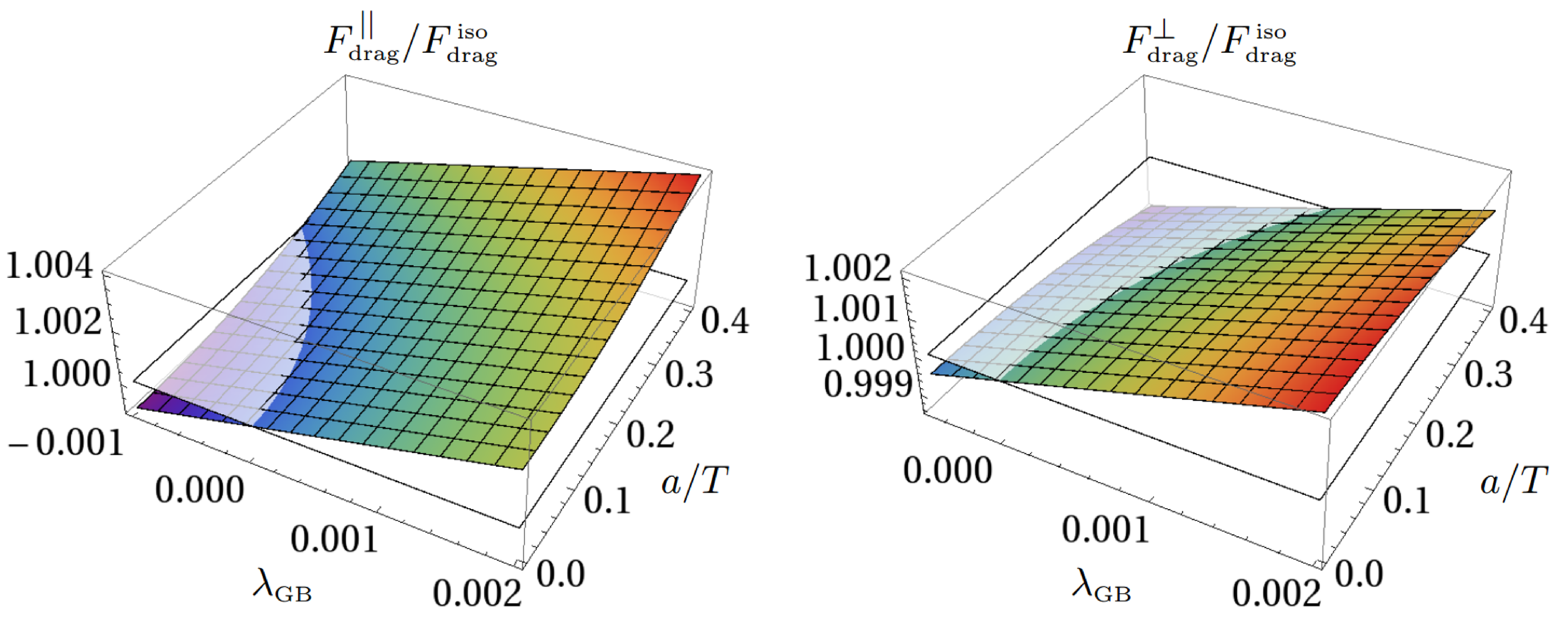

Figure 1: Drag force normalized by the isotropic result as a function of $(\lambda_{GB}, \frac{a}{T})$. Here we have fixed $v = 0.3$. Left: Motion along the anisotropic direction. Right: Motion along the direction transversal to the anisotropy.

FAPESP

Jet quenching parameter

- The **jet quenching parameter** $\hat{q}$ quantifies the change of transverse momentum of the parton per unit length when suffering multiple scattering with the medium. The non-perturbative definition of the jet quenching parameter was inspired by its perturbative calculation in the so called dipole approximation

$$W^A(\mathcal{C}) \simeq \exp\left[-\frac{L^-\ell^2}{4\sqrt{2}}\hat{q}\right],$$

where $W^A(\mathcal{C})$ is a rectangular light-like Wilson loop in the adjoint representation with sizes L^- and ℓ, with $L^- \gg \ell$.
- **Dual picture:** the jet quenching parameter is extracted from the on-shell Nambu-Goto action whose string worldsheet boundary coincides with the Wilson loop.

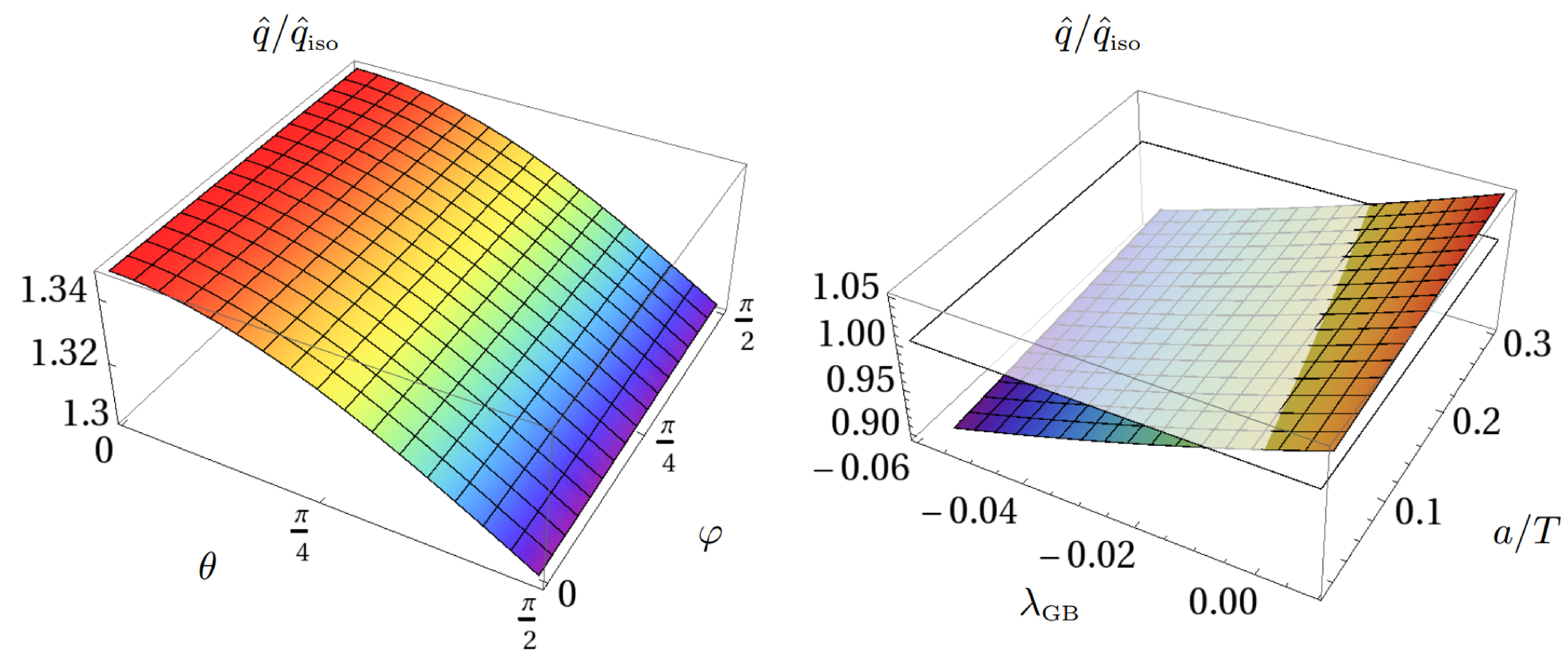

Figure 2: Left: Jet quenching parameter as a function of the angles (θ, φ) associated with the direction of motion of the quark and the direction of transversal momentum broadening, respectively. We have set $\lambda_{GB} = 0.1$ and $a/T = 0.33$. Right: The jet quenching parameter as a function of $(\lambda_{GB}, \frac{a}{T})$. We have set $\theta = \varphi = \pi/4$. Both plots were normalized by the isotropic result.

Summary and discussion

Table 1: Summary of the effects of the anisotropy and the Gauss-Bonnet coupling λ_{GB} on several observables. We also present the result for the shear viscosity over entropy density η/s previolsly obtained in [9].

	$\lambda_{GB} > 0$	$\lambda_{GB} < 0$	Anisotropy
Shear viscosity	decrease	increase	$\eta_\perp > \eta_{\|\|}$
Drag force	increase	decrease	$F_{drag}^{\perp} < F_{drag}^{\|\|}$
Jet quenching	increase	decrease	$\hat{q}_\perp < \hat{q}_{\|\|}$

- A possible heuristic interpretation of the above results is to correlate these results with the changes in the ratio η/s. At weak coupling, η/s is proportional to the mean free path. Imagining a situation where the mean free path is decreasing, we should expect an external probe to interact more with the medium, increasing the energy loss of the probe and its probability to suffer scattering. As a result, we would obtain an increase in the drag force and the jet quenching paramenter.
- In the present work, we also computed other observables, namely, the static potential between a quark-antiquark pair and the photon production rate.

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