Vol. 1 (2008) *Acta Physica Polonica B Proceedings Supplement* No 3

ADS/CFT AND RHIC PHYSICS*

Amos Yarom

Ludwig-Maximilians-Universität, Department für Physik
Theresienstrasse 37, 80333 München, Germany

(Received October 16, 2008)

We calculate the stress energy tensor of an $\mathcal{N}=4$ super-Yang–Mills plasma due to a heavy quark moving through it at constant velocity. We observe a Mach cone and a wake, and discuss these results in the context of dijet correlations.

PACS numbers: 11.25.Tq, 25.75.–q

Di-hadron correlations measured by the PHENIX Collaboration in heavy-ion collisions suggest that a shock wave is created as a quark moves supersonically through a quark–gluon plasma [1, 2]. It seems likely that in order for such a model to agree with the data, the interaction of the quark with the plasma has to be such that no wake will be formed behind the quark [2]. Though, one should note that results from STAR [3] show that the jets are broadened rather than split. Since it is difficult to analyze the precise interaction of the quark with the plasma, various approximations are used. Here we report on an analysis of the shock wave and wake created by a heavy quark moving in an $\mathcal{N}=4$ SU(N) super Yang–Mills (SYM) plasma at large N and large 't Hooft coupling.

More precisely, we calculate the energy density and Poynting vector of a heavy probe quark as it moves at constant velocity through the SYM plasma. Our method for calculating the energy momentum tensor relies on the observation that a heavy quark moving in a thermal SYM plasma has an alternate description as a string moving in a curved black hole spacetime with line element

$$ds^2 = \frac{L^2}{z^2}\left(-g(z)dt^2 + \sum_{i=1}^{3} dx_i^2 + dz^2\right)\,, \tag{1}$$

* Presented at the XXXVII International Symposium on Multiparticle Dynamics, Berkeley, USA, August 4–9, 2007.

where $g(z) = 1 - (z/z_0)^4$ [4, 5]. We have omitted a 5-sphere which will not play an important role in what follows. The coordinate z runs from 0 on the asymptotic boundary of the spacetime to z_0 on the horizon.

To describe a string moving in this background together with the response of the metric to the moving string, we vary the action $S = S_{\rm NG} + S_{\rm EH}$, where

$$\begin{aligned} S_{\rm NG} &= \frac{1}{2\pi\alpha'} \int G_{\mu\nu} \partial X^\mu \partial X^\nu d\sigma d\tau \,, \\ S_{\rm EH} &= \frac{1}{16\pi G_5} \int \sqrt{G} \left(R + \frac{12}{L^2} \right) d^5 x \,, \end{aligned} \tag{2}$$

with respect to the metric G and with respect to $X^\mu(\sigma, \tau)$, the location of a string element in terms of the internal time and space coordinates on the worldsheet. We solve the resulting equations iteratively: first for the string moving in the background 1 and then for the linear response of the metric to the string.

We denote by $G^{(0)}$ the metric corresponding to the AdS black hole background 1. In [4, 5] the equations of motion for the string embedding functions, X^μ, in this background were solved. To describe excitations of the energy momentum tensor of the plasma above its background value we need to look for the linear response of the metric to the string which we denote H

$$G_{\mu\nu} = G^{(0)}_{\mu\nu} + \frac{8\pi G_5}{L z^2} H_{\mu\nu} \,. \tag{3}$$

Plugging (3) and the solution for the string embedding, X^μ, into the Einstein equations obtained from the action S, and keeping only linear terms in H, we find

$$\mathcal{D}^{\mu\nu\sigma\tau} H_{\sigma\tau} = J^{\mu\nu} \,, \tag{4}$$

where $\mathcal{D}$ is a second order differential operator, and J comes from the string source. The boundary conditions for (4) are that the metric fluctuations vanish at the asymptotic boundary of AdS, $H(0) = 0$ (implying that there is no deformation of the boundary theory) and that there are no modes which are outcoming from the black hole horizon. Working in the axial gauge where $H_{\mu z} = 0$, the excitations of the energy momentum tensor of the SYM theory due to the moving quark, $\langle \delta T_{mn} \rangle$, are equal to the coefficient of the fourth order term in a series expansion of H_{mn} around the boundary located at $z = 0$, that is $H_{mn} = \ldots + \langle \delta T_{mn} \rangle z^4 + \mathcal{O}(z^5)$.

Solving (4) and extracting $\langle \delta T_{mn} \rangle$ proves quite difficult. One can obtain the asymptotic behavior of $\langle \delta T_{mn} \rangle$ in the close vicinity of the moving quark [6–8] and far away from it [9]. For intermediate distances we relied on a numerical solution [9–12], see Fig. 1.

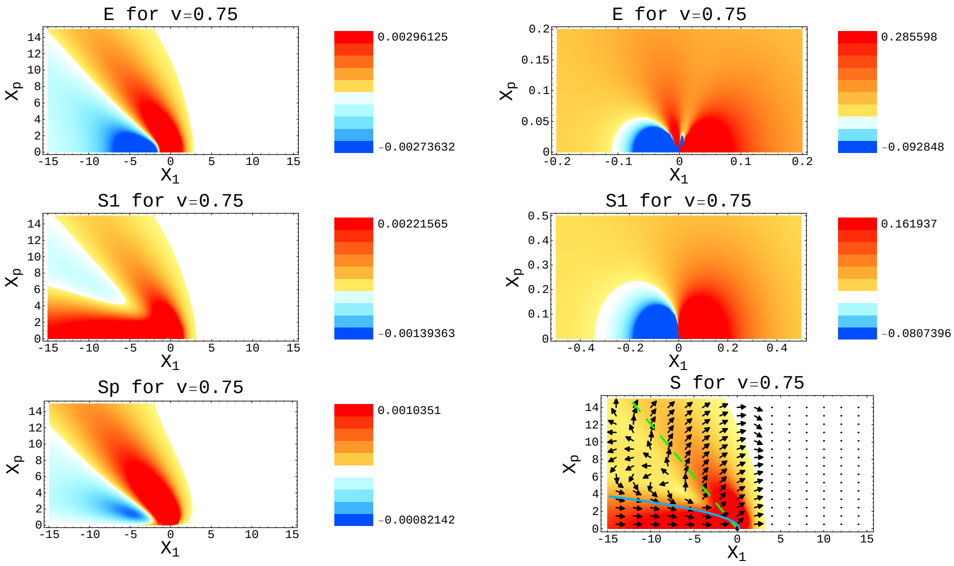

Fig. 1. Energy density and components of the Poynting vector. We use $Sp = \sqrt{S_2^2 + S_3^2}$. Length is measured in units of temperature. The lower right plot is colored according to the magnitude of $\vec{S}$, while the arrows show the direction of $\vec{S}$. The Mach cone and diffusion wake are shown in green (solid line) and blue (dashed line), respectively.

The ratio of energy going into the wake to the energy going into sound modes can be calculated once the large distance asymptotics of $\langle \delta T_{mn} \rangle$ are known [12]. It is given by $1+v^2 : 1$. This is an important quantity when considering correlations between a trigger-jet and an away-side jet. If the away-side jet is due to a quark that travelled through the quark–gluon plasma creating no wake behind it, then we expect no jets along the quark's direction of motion ("scenario 2" of [2]). On the other hand, if there is a wake behind the quark then we do expect jets along its direction of motion ("scenario 1" of [2]). The ratio $1 + v^2 : 1$ indicates that there is a strong inflow of energy from the wake implying that in the SYM theory scenario 1 will dominate over scenario 2. Recall that scenario 2 favors the PHENIX data [1].

The critic may now argue that since QCD is rather different from the $\mathcal{N} = 4$ SYM theory, the ratio $1 + v^2 : 1$ is perhaps irrelevant to the hydrodynamic analysis of [2]. A partial reply can be found in [13] where the ratio of energy entering from the wake, to energy going into sound was calculated for a class of theories which have an asymptotically AdS black hole dual and scalar matter. In all these theories the ratio was $1 + v^2 : 1$ suggesting that it may be universal and can apply to QCD.

I would like to thank my collaborators S. Gubser and S. Pufu without whom this work could not have taken place and also M. Haack for many motivating discussions. I am supported in part by the German Science Foundation and by the Minerva Foundation.

REFERENCES

[1] S.S. Adler *et. al.* [PHENIX Collaboration], *Phys. Rev. Lett.* **97**, 052301 (2006) [nucl-ex/0507004].

[2] J. Casalderrey-Solana, E.V. Shuryak, D. Teaney, *J. Phys. Conf. Ser.* **27**, 22 (2005) [hep-ph/0411315].

[3] J. Adams *et. al.* [STAR Collaboration], *Phys. Rev. Lett.* **95**, 152301 (2005) [nucl-ex/0501016].

[4] C.P. Herzog, A. Karch, P. Kovtun, C. Kozcaz, L.G. Yaffe, *J. High Energy Phys.* **07**, 013 (2006) [hep-th/0605158].

[5] S.S. Gubser, *Phys. Rev.* **D74**, 126005 (2006) [hep-th/0605182].

[6] A. Yarom, *Phys. Rev.* **D75**, 125010 (2007) [hep-th/0702164].

[7] S.S. Gubser, S.S. Pufu, hep-th/0703090.

[8] A. Yarom, *Phys. Rev.* **D75**, 105023 (2007) [hep-th/0703095].

[9] J.J. Friess, S.S. Gubser, G. Michalogiorgakis, S.S. Pufu, *Phys. Rev.* **D75**, 106003 (2007) [hep-th/0607022].

[10] S.S. Gubser, S.S. Pufu, A. Yarom, *J. High Energy Phys.* **09**, 108 (2007) [arXiv:0706.0213 [hep-th]].

[11] P.M. Chesler, L.G. Yaffe, *Phys. Rev. Lett.* **99**, 152001 (2007) [arXiv:0706.0368[hep-th]].

[12] S.S. Gubser, S.S. Pufu, A. Yarom, arXiv:0706.4307[hep-th].

[13] S.S. Gubser, A. Yarom, arXiv:0709.1089 [hep-th].