Imaginary potential of heavy quarkonia in rotating matter from holography

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Outline

- Motivations
- AdS/CFT correspondence (holography)
- Imaginary potential in rotating matter
- Conclusion and outlook

Motivations

- The QGP is the hottest and the less viscous (or almost perfect) fluid ever created in nature
- The QGP is strongly coupled and thus calculational tools for non-perturbative methods are needed
- The holographic calculations, $\eta/s = 1/4\pi$, being at least one order of magnitude smaller than perturbative calculations

AdS/CFT correspondence (holography)

Adv. Theor. Math. Phys. 2 (1998) 231–252
Adv. Theor. Math. Phys. 2 (1998) 253–291
Phys. Lett. B428 (1998) 105–114

$N = 4$ SYM on the boundary $\Leftrightarrow$ Type IIB string theory in the bulk

$$\lambda \equiv N_c g_{YM}^2 = \frac{1}{\alpha'^2} \quad \left(\text{string tension} = \frac{1}{2\pi\alpha'}\right)$$

$$\frac{\lambda}{N_c} = 4\pi g_s$$

$$< e^{\int d^4x \phi_0(x) O(x)} > = Z_{\text{string}}[\phi(x,0) = \phi_0(\text{x})]$$

In the limit $N_c \to \infty$ and $\lambda \to \infty$

$$Z_{\text{string}}[\phi(x,0) = \phi_0(x)] = e^{-I_{\text{sugra}}[\phi]} |_{\phi(x,0)=\phi_0(x)}$$

$$I_{\text{sugra}}[\phi] = \text{classical supergravity action}$$

AdS/CFT correspondence (holography)

The AdS/CFT dictionary

AdS_d	$(d-1)$-dimensional Gauge Theory	Description
l	$\sqrt{\alpha'}\,\lambda^{1/4}$	Radius of curvature of AdS_d and S^d
ℓ_s	$\sqrt{\alpha'} \equiv \lambda^{-1/4} l$	Fundamental string length scale
T_0	$1/2\pi\alpha'$	String tension
$(l/\ell_s)^4$	λ	't Hooft coupling[a]
r_H	$4\pi l^2 T/(d-1)$	Radial position of the black hole horizon
$(d-1)r_H/4\pi l^2$	$T \equiv 1/\beta$	Temperature of the gauge theory[b]
$r_c \equiv (r_s + \ell_0)$	$2\pi\alpha'(M_{rest} + \Delta m)$	Minimal radius of D7-brane[c]
$T_0 r_H$	$\Delta m(T)$	Thermal rest mass shift
$T_0(r_c - r_H)$	$M_{rest}(T)$	Static thermal mass of external particle[d]

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AdS/CFT correspondence (holography)

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QCD vs N=4 SYM

	QCD	SYM
	3	>>1
t'Hooft coupling	5.5-18.8	>>1
Quarks	Fundamental	Adjoint
Conformal symmetry	No	Yes at zero T No at nonzero T
Supersymmetry	No	Yes at zero T No at nonzero T

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Imaginary potential in rotating matter

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- A useful probe of the QGP involves quarkonium ($Q\bar{Q}$). For a long time, it was believed that the suppression of quarkonium production in HICs probes the Debye screening of the potential.
- However, systematic studies using thermal field theory showed that in addition to the Debye screening, the in-medium $Q\bar{Q}$ potential also develops a thermal imaginary part, which is a reflection of quarkonium dissociation[JHEP 03 (2007) 054]

Imaginary potential in rotating matter

- the QGP produced in (typical) noncentral heavy-ion collisions may carry a nonzero angular momentum (related to colliding nuclei) on the order of 10^4-$10^5\hbar$ with local angular velocity in the range of 0.01-0.1GeV

The STAR Collaboration, Nature 548 (2017) 62–65.
Z.T. Liang, X.N. Wang, Phys. Rev. Lett. 94 (2005) 102301; 96 (2006) 039901(E).
F. Becattini, F. Piccinini, J. Rizzo, Phys. Rev. C 77 (2008) 024906.
X.G. Huang, P. Huovinen, X.N. Wang, Phys. Rev. C 84 (2011) 054910.
L.G. Pang, H. Petersen, Q. Wang, X.N. Wang, Phys. Rev. Lett. 117 (2016) 192301.

- An understanding of how the computations are affected by angular velocity may be essential for more precise theoretical predictions

Imaginary potential in rotating matter

- We here consider the imaginary potential of $Q\bar{Q}$ from thermal fluctuations in a holographic QCD model (i.e., a soft wall model)

and

- analyze how angular velocity affects imaginary potential and quarkonia dissociation

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Imaginary potential in rotating matter

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We employ a type of soft wall model, whose background is

$$ds^2 = \frac{r^2 h(r)}{R^2}[-f(r)dt^2 + dx^2 + dy^2 + dz^2] + \frac{R^2 h(r)}{r^2 f(r)} dr^2,$$

$$f(r) = 1 - \frac{r_h^4}{r^4}, \qquad h(r) = e^{c^2 R^4 / r^2},$$

where R is the AdS radius (hereafter we set $R = 1$). r denotes the fifth coordinate. The boundary is $r = \infty$. The event horizon is $r = r_h$, defined by $f(r_h) = 0$. $h(r)$ is the warp factor, determining the characteristics of the soft wall model. c refers to the deformation parameter, determining the deviation from conformality.

Imaginary potential in rotating matter

Next, we extend the metric to a rotating case by operating a Lorentz boost in the $t-\phi$ plane

$$t \to \gamma(t + \omega l^2 \phi), \qquad \phi \to \gamma(\phi + \omega t), \qquad \gamma = \frac{1}{\sqrt{1-(\omega l)^2}},$$

where ϕ is the angular coordinate describing the rotation. ω is the angular velocity. l is the radius of the rotating axis. For ease of calculation, we will take $l=1GeV^{-1}$

The Hawking temperature of the black hole is

$$T = \left| \frac{\lim_{r\to r_h} \frac{1}{2}\sqrt{\frac{g^{11}}{-\hat{g}^{00}}}\hat{g}_{00,1}}{2\pi} \right| = \frac{r_h}{\pi}\sqrt{1-\omega^2}.$$

Imaginary potential in rotating matter

The expectation value of the static (temporal) Wilson loop is given by

$$W(C) = \frac{1}{N_c} Tr\, P e^{i \int A_\mu dx^\mu},$$

$$< W(C) > \sim e^{iT V_{QQ}}.$$

According to AdS/CFT, the $< W(C) >$ in a strongly coupled gauge theory

$$< W(C) > \sim Z_{str},$$

On the other hand, in the supergravity limit,

$$Z_{str} \sim e^{iS_{str}},$$

Imaginary potential in rotating matter

Next, we study the Imaginary potential from using thermal fluctuations

J. Noronha, A. Dumitru, Phys. Rev. Lett. 103 (2009) 152304.

$$r(x) = r_c(x) \to r(x) = r_c(x) + \delta r(x),$$

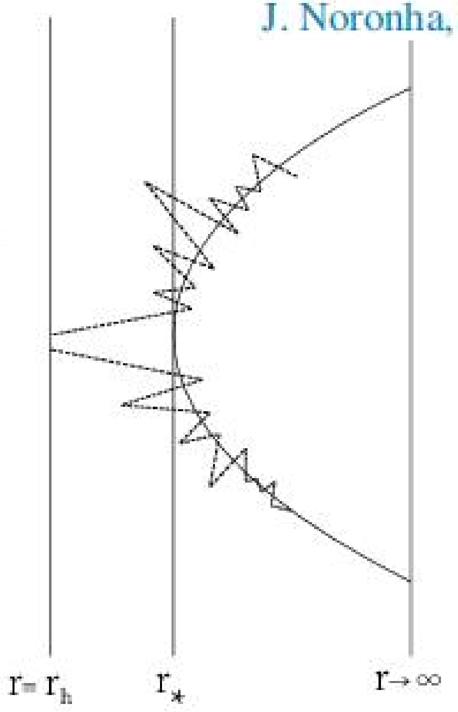

FIG. 1: The thermal fluctuations (dashed line) around the classical configuration (solid line).

where $r_c(x)$ solves $\delta S = 0$. Fig. 1 shows a diagram describing thermal fluctuations, one can see that if r_* is close enough to the horizon, the fluctuations of long wavelength may reach it.

Imaginary potential in rotating matter

Result 1: increasing ω, the inter-quark distance becomes shorter

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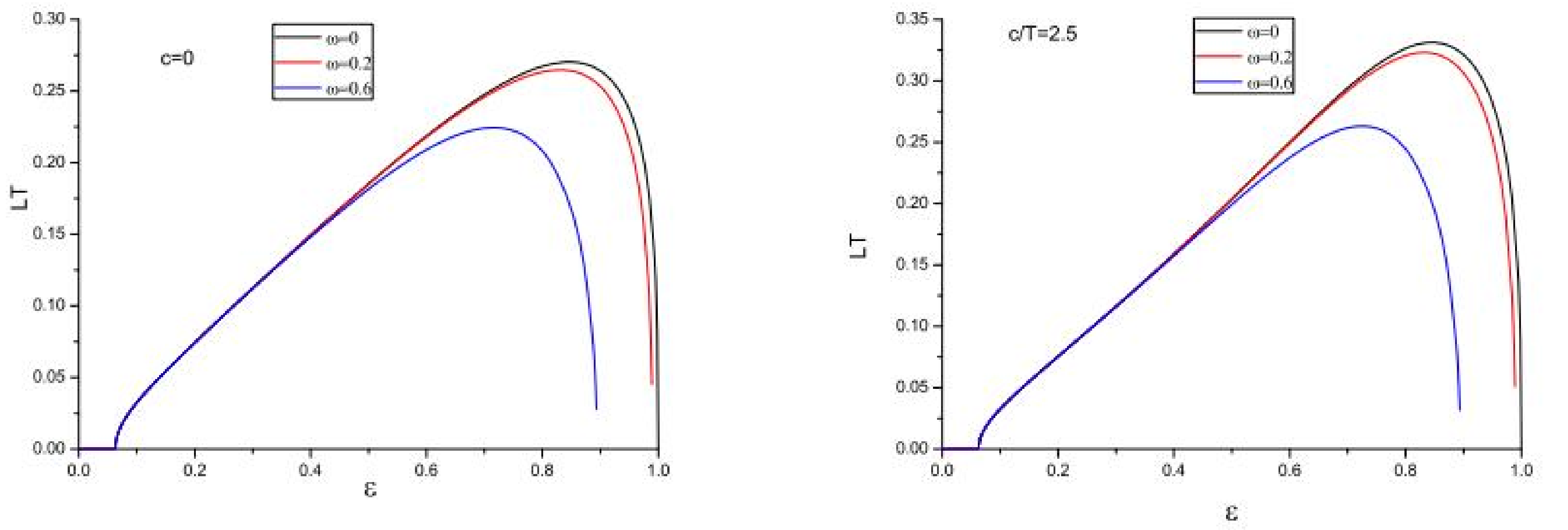

Fig. 2. Left: LT versus ε, in both panels from top to bottom, $\omega = 0, 0.2, 0.6$ GeV, respectively.

Imaginary potential in rotating matter

Result 2: increasing ω, the onset of ImV/(√λT) happens at smaller LT, implying the suppression will be stronger

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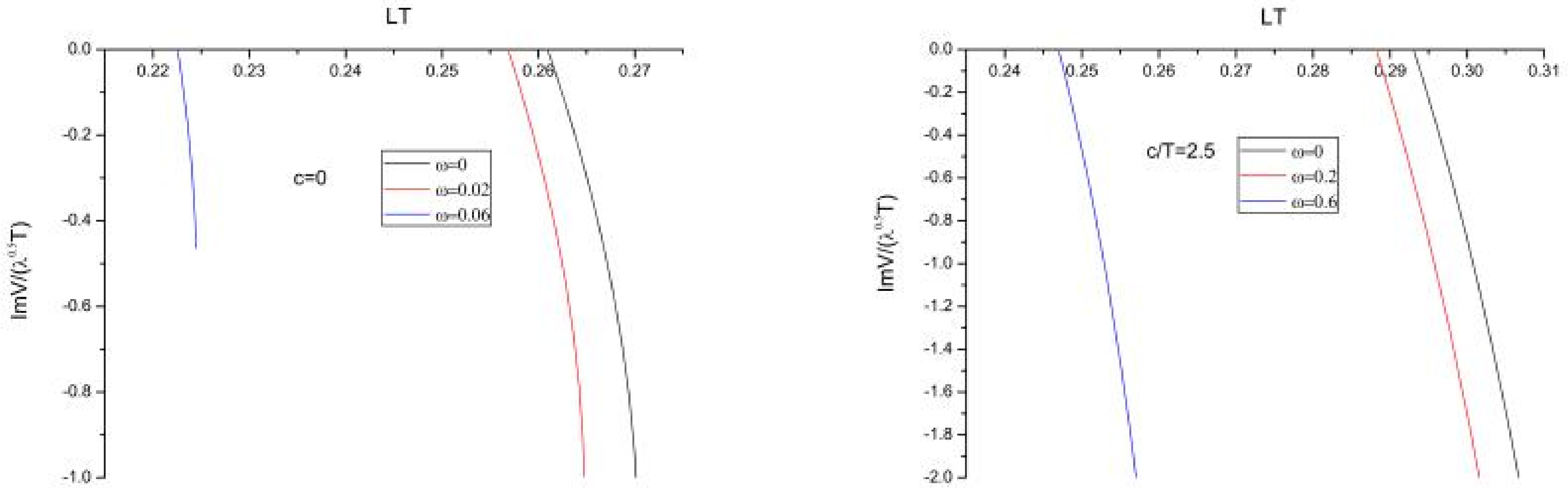

Fig. 4. $\mathrm{Im}V/(\sqrt{\lambda}T)$ versus LT, in both panels from right to left, $\omega = 0, 0.2, 0.6$ GeV, respectively.

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Conclusion and outlook

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- An understanding of how the computations are affected by angular velocity may be essential for more precise theoretical predictions
- By increasing ω, the inter-distance of $Q\overline{Q}$ decreases
- The presence of ω decreases the onset of imaginary potential thus enhancing quarkonia dissociation

Conclusion and outlook

- The results are in agreement with previous findings for the moving $Q\overline{Q}$ case   S.I. Finazzo, J. Noronha, J. High Energy Phys. 01 (2015) 051
- Final conclusion from imaginary potential: moving or rotating quarkonia dissociate easier than the static case
- Outlook: are the results consistent with

  other rotation schemes? (e.g. Kerr-AdS)

  other dissolution mechanisms? (e.g. entropic force etc)

Thanks

Hope your comments and criticism