Universidad de Valparaíso CHILE

INSTITUTO FISICA Y Astronomía

Instituto de Física y Astronomía
Facultad de Ciencias, Universidad de Valparaíso, Chile.

Dirección: Av. Gran Bretaña 1111, Playa Ancha, Valparaíso, Chile.
Teléfono: +56 32 2508426

Holographic description of QGP using AdS/QCD Models

Miguel Ángel Martín Contreras
With A. Vega

Physics and Astronomy Institute, Universidad de Valparaíso, Chile

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Outline

QGP Generalities

Generalities

E. Shuryak, 2004.
J. Adams et. al. (RHIC), 2005.
S. S. Adler et. al. (RHIC), 2007.

- It is a deconfined state of QCD created in heavy ion collisions, where partons are almost free.
- It behaves as a perfect fluid, i.e., $\frac{S}{V} = \frac{1}{4\pi}$ and $\eta = 0$.
- It is a strongly coupled system.
- It is expected to be formed at $T_c = 175$ MeV, when light mesons melt down.
- Theoretical approaches: lattice QCD, real time methods, bootstrap models, χ-PT, Thermal Loop and other effective lagrangians.

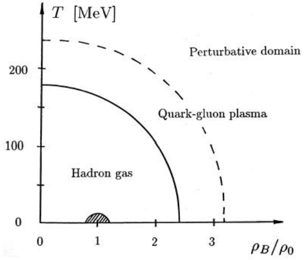


Figure 1: QCD phase diagram

AdS/CFT in a sentence

A possible definition

AdS/CFT correspondence can be defined as a tool to explore non-perturbative physics using gravity.

...or if you want...

AdS/CFT is the duality that connects a $d+1$–QFT at strong coupling with $d+2$–gravity at weak coupling (MAGOO,1998).

Both are valid *intuitive* definitions.

AdS/QCD models

General Idea

AdS/QCD models are a bottom-up approach to introduce confinement and asymptotic freedom into holography by including a form to break softly the conformal invariance.

These approaches have been successful to describe:

At $T = \mu = 0$

- Hadronic spectra
- EM form factors
- Decay constants for heavy mesons
- Structure functions.

Finite T and μ:

- Confinement/Deconfinement phase Transitions.
- Melting of Hadrons at finite T and finite μ
- In-medium (Nuclear) properties
- QCD Thermodynamics

AdS/CFT Universality

Top/down approaches have been successful describing the perfect fluid limit of a CFT (Kotvun, Mateos, Erdmenger, etc). But these approaches do not have a consistent form to introduce confinement or asymptotic freedom phenomenology.

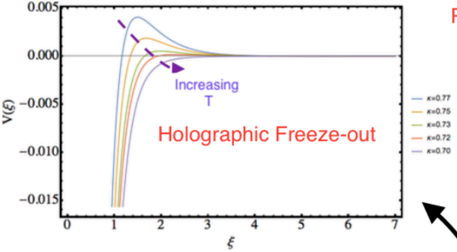
AdS/QCD models "plasticity"

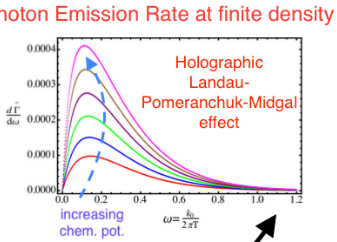
Since AdS/QCD models are "softly not conformal", it is possible to model an "almost perfect fluid" as the one observed in HIC.

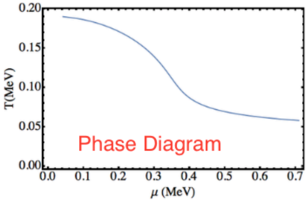
The idea is to use the background geometry to model the fluid properties of the QGP: fluid/gravity duality.

Let us start to model holographically the QGP!

Holographic (toy) model for emitted photons in the fireball







$$dS^2 = \frac{\pi^2 T^2 R^2}{u^2}\left[\frac{d\,u^2}{f(u)} - f(u)\,dt^2 + d\vec{x}\cdot d\vec{x}\right],$$

$$I_{\text{Photons}} = -\frac{1}{4\,g_\gamma^2}\int d^5x\,\sqrt{-g}\,e^{-\Phi(u)}\,F_{mn}\,F^{mn}.$$

Trailing strings as moving quarks

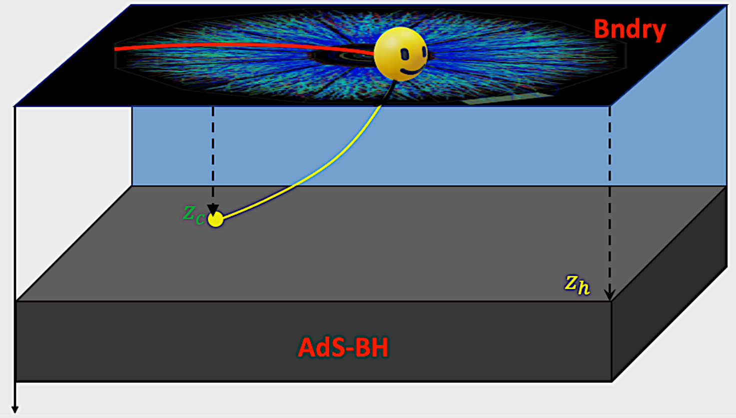


Figure 2: Quark moving across the QGP medium and its holographic description

Holographic Model

For simplicity, we will asume that the quark is moving on the x_1-direction on the boundary with a velocity $v\,\hat{x}_1$.
So, in the static gauge, we can write

$$x_1\,(z) = v\,t + \xi\,(z)$$

Under this gauge choice, the embedding metric γ_{ab} emerges as

$$dS^2 = \frac{R^2}{z^2}\left[-f\left(1-\frac{v^2}{f}\right)dt^2 + \frac{1}{f}\left(1+f\,\xi'^2\right)dz^2 + 2\,v\,\xi'\,dt\,dz\right] = \gamma_{ab}\,d\sigma^a\,d\sigma^b$$

The worldsheet metric is defined by the coordinate choice: $\sigma_a = \{t, z\}$.
From this metric we will obtain an expression for the drag force in the soft wall model context.

Our starting point will be the Nambu Goto action defined for the embedding metric given above:

$$\begin{aligned} I_{\rm NG} &= -\frac{1}{2\,\pi\,\alpha'}\int d^2\sigma\, e^{-\Phi(z)}\sqrt{-\det\gamma} \\ &= -\frac{1}{2\,\pi\,\alpha'}\int d^2\sigma\,\frac{e^{2\,B(z)}}{z^2}\sqrt{1-\frac{v^2}{f}+f\,\xi'^2} \end{aligned}$$

where $B\left(z\right) = -\frac{\Phi(z)}{2} + \log\frac{R}{z}$ and $\Phi\left(z\right) = \kappa^2\,z^2$ is the static dilaton profile. The Drag Force comes from the canonical conjugate momentum $\Pi^z_{x_1}$ as follows:

$$F_{\rm Drag} = \Pi^z_{x_1} = -\frac{1}{2\,\pi\,\alpha'}\frac{e^{2\,B(z)}}{z^2}\frac{\xi'\,f}{\sqrt{1-\frac{v^2}{f}+f\,\xi'^2}} = -\frac{e^{2B(z_c)}}{2\,\pi\,\alpha'\,z_c^2}\sqrt{f\left(z_c\right)}, \tag{1}$$

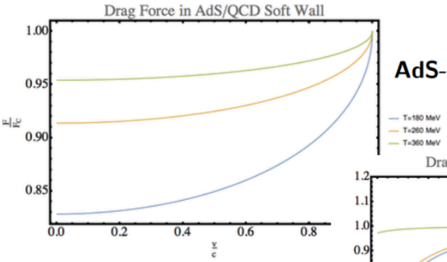
where z_c is critical point that defines the region in the bulk where the string is stretching, and it is defined as $v^2 = f(z_c)$.

Some Remarks

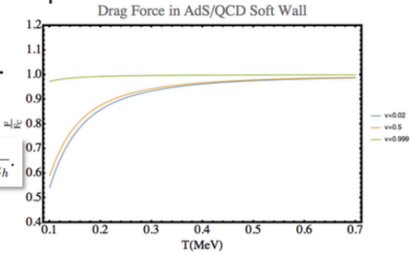
- This z_c defined by the kinematical constrain $f(z_c) = v^2$. i.e. it depends on the thermal conditions for the plasma modeled by the metric.
- z_c can be considered as the "probe" that captures the medium effect on the moving quark since the string end is affected by the BH gravity.

Now, we will focus on two different geometric backgrounds: AdS-Schwartzchild and AdS-Reissner-Nordstrom geometries to see the thermal and chemical potential effects.

AdS-Schwartzschild background



AdS-Schwartzchild Geometry



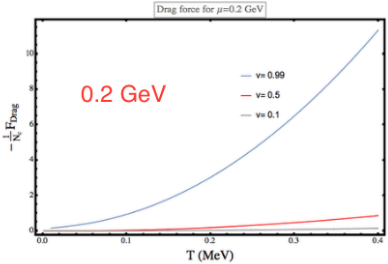
In this case: $f(z) = 1 - \frac{z^4}{z_h^4}$ with $T = \frac{1}{\pi z_h}$.

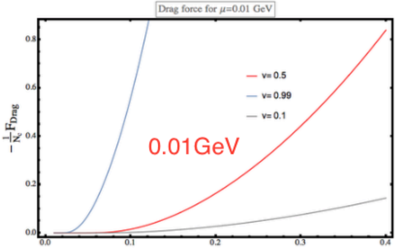
AdS-Reissner Nordstrom background

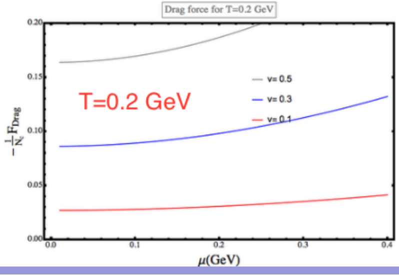
AdS-Reissner-Nordstrom Geometry

In this case: $f(z) = 1 - \left(1 + Q^2\right)\frac{z^4}{z_h^4} + Q^2\frac{z^6}{z_h^6}$

with $T = \frac{1}{\pi\, z_h}\left(1 - \frac{Q^2}{2}\right)$ and $\mu = \frac{Q}{z_h}$.







Conclusions

- AdS/QCD soft wall model provides a simple framework to study the QGP phenomenology at finite T and finite μ.
- Holographic realization of the Landau-Pomeranchuk-Midgal Effect and the drag force was done.
- Medium properties were studied by fixing the kinematical constrain $f\left(z_c\right) = v^2$.

Future work

Things to do next:

- to implement the membrane paradigm for in-medium correletors (to address linear response).
- To calculate jet quenching.
- To calculate other thermodynamical and fluid quantities.
- To introduce anisotropies.
- To use other BH backgrounds as the non-commutative ones.

Thank you!