Confinement/Deconfinement Phase Transitions in Strongly Coupled Anisotropic Theories

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Outline

Short talk: therefore bottom-up presentation

- Strongly coupled anisotropic theory.
  - ✓ Unequal diagonal energy momentum tensor elements for the spatial dimensions. Unequal pressures.
- How the theory looks like and how to obtain it?
  - ✓ 4d $SU(N)$ gauge theory in the large N_c-limit.
  - ✓ Its dynamics are affected by a scalar operator $\mathcal{O} \sim TrF^2$.
  - ✓ Anisotropy is introduced by another operator $\tilde{\mathcal{O}} \sim \theta(x_3) TrF \wedge F$ with a space dependent coupling.
  - ✓ On the gravity dual side a "backreacting" scalar field depending on spatial directions axion; and a non-trivial dilaton.

- Eventually an Einstein-Axion-Dilaton theory in 5 dimensions with a non-trivial potential.

  Theory Evolution:

  Non-Confining:

  (Azeyanagi, Li, Takayanagi, 2009; Mateos, Trancanelli, 2011; Jain, Kundu, Sen, Sinha, Trivedi, 2015;...)

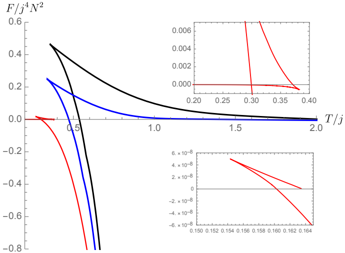
  Confining:

  (D.G., Gursoy, Pedraza, 2017)

- May have heard already about such theories since they violate well known universal relations:
  - ✓ Shear Viscosity over entropy density ratio parametrically lower than KSS bound: $1/4\pi$.
    (Rebhan,Steineder 2011; Jain, Samanta, Trivedy 2015; D.G., Gursoy, Pedraza, 2017;...)
  - ✓ Langevin Coefficient inequality for heavy quark motion in the anisotropic plasma $\kappa_L ><\kappa_T$.
    (Gursoy, Kiritsis, Mazzanti, Nitti 2010; D.G, Soltanpanahi, 2013a, 2013b)
  - ✓ ...

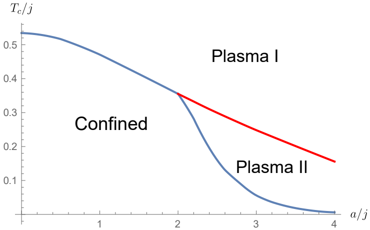
Confinement/Deconfinement Phase transitions

- The free energy of the theories vs the temperature T for different anisotropy (α/j=0,1,3):



- Horizontal Axis: Confining Phase.
- Upper Branch: Black hole A:Deconfining Plasma Phase.
- Lower Branch: Black hole B:Deconfining Plasma Phase.
- $a/j \simeq 2$: A critical value above which a richer structure in the phase diagram exist.

- The Critical Temperature of the theories vs the anisotropy gives:



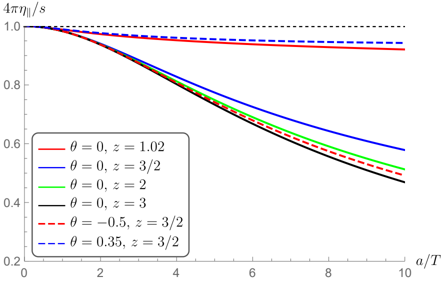
- The T_c is reduced in presence of anisotropies of the theory.

So far: Findings and Proposal

- The $Tc(\alpha)$ decrease with α, resembling the phenomenon of inverse magnetic catalysis where the confinement-deconfinement temperature decreases with the magnetic field B.
- No charged fermionic degrees of freedom in our case; our plasma is neutral.
- Our findings suggest that the anisotropy by itself could instead be the cause of lower T_c in presence of anisotropies.

η/s for our theory: Dependence on the Temperature.

The shear viscosity over entropy ratio for arbitrary (z, θ).



- The ratio depends on the temperature at $\alpha/T \gg 1$ as

$$\frac{\eta_{13}}{s} \sim \left(\frac{T}{\tilde{\alpha}|1+3z-\theta|}\right)^{2-\frac{2}{z}} .$$

- The range of the temperature power is $[0, \infty)$.

The Anisotropic Theory

Consider a generalized (reduced) Einstein-Axion-Dilaton action with a potential for the dilaton and an arbitrary coupling between the axion and the dilaton:

$$S=\frac{1}{2\kappa^2}\int d^5x\sqrt{-g}\left[R-\frac{1}{2}(\partial\phi)^2+V(\phi)-\frac{1}{2}Z(\phi)(\partial\chi)^2\right].$$

The eoms read

$$R_{\mu\nu}-\frac{1}{2}Rg_{\mu\nu}=\frac{1}{2}\partial_\mu\phi\partial_\nu\phi+\frac{1}{2}Z(\phi)\partial_\mu\chi\partial_\nu\chi-\frac{1}{4}g_{\mu\nu}(\partial\phi)^2-\frac{1}{4}g_{\mu\nu}Z(\partial\chi)^2+\frac{1}{2}g_{\mu\nu}V(\phi)\ ,$$

$$\frac{1}{\sqrt{-g}}\partial_\mu\left(\sqrt{-g}g^{\mu\nu}\partial_\nu\phi\right)=\frac{1}{2}\partial_\phi Z(\phi)(\partial\chi)^2-V'(\phi)\ ,$$

$$\frac{1}{\sqrt{-g}}\partial_\mu\left(\sqrt{-g}g^{\mu\nu}\partial_\nu\chi\right)=0\ .$$

Where the functions

$$V(\phi)=12\cosh(\sigma\phi)-6\sigma^2\phi^2,\qquad Z(\phi)=e^{2\gamma\phi},$$

((Gubser, Nellore), Pufu, Rocha 2008a,b)

Note: For $\sigma=0,\gamma=1$ the action and the solution of eoms, are of IIB supergravity. *(Mateos, Trancanelli, 2011)*

Let us apply the black hole background ansatz

$$ds^2 = \frac{e^{-\frac{1}{2}\phi(u)}}{u^2}\left(-\mathcal{F}\mathcal{B}\,dt^2 + dx_1^2 + dx_2^2 + \mathcal{H}dx_3^2 + \frac{du^2}{\mathcal{F}}\right),$$
$$\chi = \alpha x_3\,, \qquad \phi = \phi(u)\,,$$

$\phi(u), \mathcal{B}(u), \mathcal{F}(u), \mathcal{H}(u)$ four functions to be found, and α is the constant anisotropic parameter, u_h is the black hole horizon(related to the temperature of the theory).

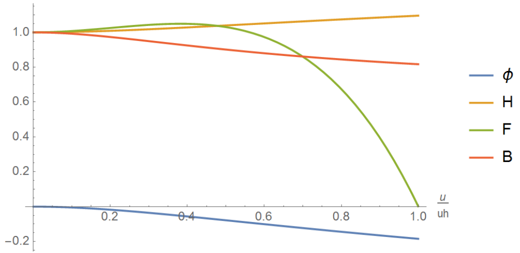
Note:
The linear axion simplifies tremendously the system of equations!

Solve the system...

Solutions: A demonstration

- Fixing (γ, σ) and α and u_h we get the metric flow from boundary to horizon:

$$ds^2 = \frac{e^{-\frac{1}{2}\phi(u)}}{u^2}\left(-\mathcal{F}\mathcal{B}\, dt^2 + dx_1^2 + dx_2^2 + \mathcal{H} dx_3^2 + \frac{du^2}{\mathcal{F}}\right),$$



- In sufficiently high temperatures, $T \gg \alpha$ for $\gamma = 1, \sigma = 0$ the Einstein equations can be solved analytically:

$$\mathcal{F}(u) = 1 - \frac{u^4}{u_h^4} + \alpha^2 \frac{1}{24 u_h^2}\left[8u^2(u_h^2 - u^2) - 10u^4 \log 2 + (3u_h^4 + 7u^4)\log\left(1 + \frac{u^2}{u_h^2}\right)\right]$$

$$\mathcal{B}(u) = 1 - \alpha^2 \frac{u_h^2}{24}\left[\frac{10u^2}{u_h^2 + u^2} + \log\left(1 + \frac{u^2}{u_h^2}\right)\right], \quad \mathcal{H}(u) = \left(1 + \frac{u^2}{u_h^2}\right)^{\frac{\alpha^2 u_h^2}{4}}.$$

Conclusions

- ✓ We have presented Confining Anisotropic theories and studied the confinement/deconfinement phase transitions.
- ✓ There are certain stability conditions that constrain the parameters of the theory.
- ✓ The Confinement/Deconfinement phase transitions occur at lower critical Temperature as the anisotropy is increased!
- ✓ We suggest that the anisotropy by itself could instead be a cause of inverse magnetic catalysis.
- ✓ The shear viscosity over entropy density ratio, takes values parametrically lower than $1/4\pi$, and depends on the Temperature as $T^{2-2/z}$.
- ✓ The diffusion (buttery velocity) and growth of chaos occurs faster than isotropic systems.
- Several ways to probe the theory (Mesons, Energy loss of Quarks, Diffusion of Quarks, Speed of Sound, Entanglement Entropy...).

(D.G 2012,...)

Thank you!