Holography vs (some) observables of Yang-Mills plasma

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based on a paper with H. Verschelde (Gent Uni)

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Motivation

Large-$N_c$ Yang-Mills in **infrared**
is in the same universality class

as Witten-Sakai-Sugimoto model
with an extra dimension in UV, $\Lambda_{UV} \sim \Lambda_{QCD}$

Hence, should go to the scale

$$\Lambda_{\text{hydro}} \ll \Lambda_{QCD}$$

and are left with hydrodynamics alone
(nonperturbative at that)
Reminder on "Instantons vs $Q_{\text{top}}^2$"

\[
< Q_{\text{top}}^2 >_{\text{vac}} \geq 0, \text{ or } \int d^4 x \ < G\tilde{G}(x), G\tilde{G}(0) >_{\text{vac}} \geq 0,
\]

where $Q_{\text{top}} = (\text{const}) \int d^4 x \ G^a_{\mu \nu} \tilde{G}^a_{\mu \nu}(x)$, saturated by

\[
\int d^4 x \ < G\tilde{G}(x), G\tilde{G}(0) >_{\text{instanton}} > 0
\]

however, from the unitarity in Euclidean space

\[
\int d^4 x \ < G\tilde{G}(x), G\tilde{G}(0) >_{\text{vac}} < 0, \ x \neq 0
\]

Hence

\[
< G\tilde{G}(x), G\tilde{G}(0) >_{\text{instanton}} \rightarrow \delta^4(x)
\]
From $Q_{\text{top}}$ to momentum density $T_{0i}$?

Instead of $3d$ consider $4d$, i.e. $\omega \equiv 0$, $q \to 0$, $\int d\tau \to 1/T$

$$<T^2_{0i}>_{3d} \geq 0, \text{ or } \int d^3x <T_{0i}(x), T_{0i}(0)>_{\text{therm vac}} \geq 0$$

From unitarity and in Euclidean space

$$<T_{0i}(x), T_{0i}(0)>_{\text{therm vac}} < 0 \text{ if } x \neq 0$$

Hence

$$<T_{0i}(x), T_{0i}(0)>_{\text{non-pert}} = \text{Local in } x \geq 0$$

What is replacement, if any, for instantons?
More on holography, $T = 0$ first

- common feature: extra $z$ coordinate, conjugate to physical scale. Confinement $\leftrightarrow$ horizon $z_H$, $z < z_H$
- specific feature: extra, not-needed compact $x_4$. Wrapping around $x_4$, $\rightarrow Q_{top} \neq 0$
  Once wrapped states are (anti)instantons
- Cigar-shape geometry:

$$R_{x_4}(z \rightarrow z_{\text{horizon}}) \rightarrow 0$$

Wrapping costs nothing at the horizon—instantons are free in infrared
Holography vs (some) observables of Yang-Mills plasma

Holography, deconfining phase

- Cigar-shape \((z, x_4) \rightarrow \text{cigar-shape} (z, \tau)\),

\[
R_\tau(z \rightarrow z_H) \rightarrow 0, \quad R_{x_4}(z) = \text{const}
\]

- Phase transition \(\equiv 4d \rightarrow 3d\) for non-pert. physics (M. Chernodub, A. Gorsky, A. Nakamura, A. Zhitnitsky...)

- Once-wrapped around compact \(\tau\)-coordinate is the thermal scalar (of B. Sathiapalan, Y. Kogan, J. Atick + E. Witten..) It is free in infrared

- Condensation of the thermal scalar near horizon, (J. Barbon + E. Rabiovici, G. Horowitz, E. Silverstein..)
"Euclidean superfluidity"

Criterion of superfluidity:

$$\lim_{q \to 0} < T_{0i}, T_{0j} > \sim \frac{q_i q_j}{q^2} ,$$

(with no local term)
Condensation of the thermal scalar (3d complex field) would produce a 3d GN boson and superfluidity

However, because everything is in the Euclidean the sign is wrong (anti-unitary).
Similarity to instantons and topological charge
Liquid on the stretched horizon

For measurements with poor resolution, properties of Y-M plasma are predicted to be the same as of liquid on the stretched horizon

\[
T_{ab} = \sqrt{X} \gamma_{ab} + \frac{1}{\sqrt{X}} \partial_a \phi \partial_b \phi
\]

where \( X = - (\partial \phi)^2 \), \( ds^2 = \gamma_{ab} dx^a dx^b = - r_c d\tau^2 + dx_i dx^i \)

(G. Compere et al. 1103.3022)

Predictions:

\[
\epsilon = 0, \ p \neq 0, \ p \sim (r_c)^{-1/2}
\]

+ Euclidean superfluidity
(Quasi)-comparison with the data

Not much data but:

- there seems to be a wrong-sign local non-pert contribution in the correlator of momentum-densities (H.B. Meyer, arXiv:0907.4095)
- Trace of the energy-momentum tensor, $\epsilon - 3p$ was measured separately for the defects (center vortices)

\[
(\epsilon - 3p)_{\text{non-pert}} < 0 \quad , \quad |(\epsilon - 3p)_{\text{non-pert}}| \sim (\text{large})
\]

(M. Chernodub et al., arXiv:0807.5012)