Cold holographic matter and color symmetry breaking

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based on work with Antón Faedo, David Mateos, Christiana Pantelidou
[latest arXiv1707.06989]

PASCOS, Cleveland, June 5$^{\text{th}}$ 2018

Context of this talk

- Study strongly coupled field theories is a hard task
- But may be of interest in astrophysical setups or condensed matter models
- The purpose of this talk is to start studying the characteristics of a particular type of phase: those with spontaneous breaking of the gauge group (CSC)
- To do this in a *first principles* manner, I will resort to string theory, in particular holography

Motivation

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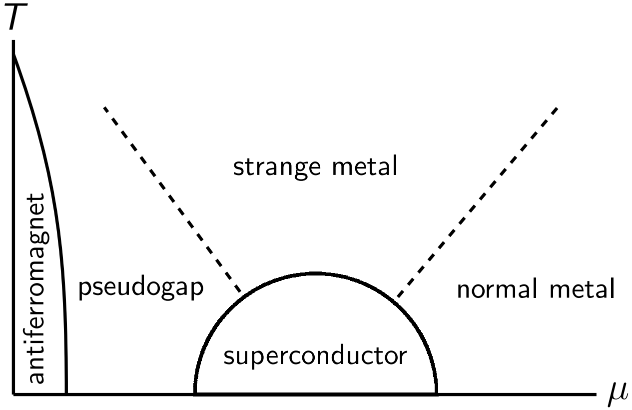
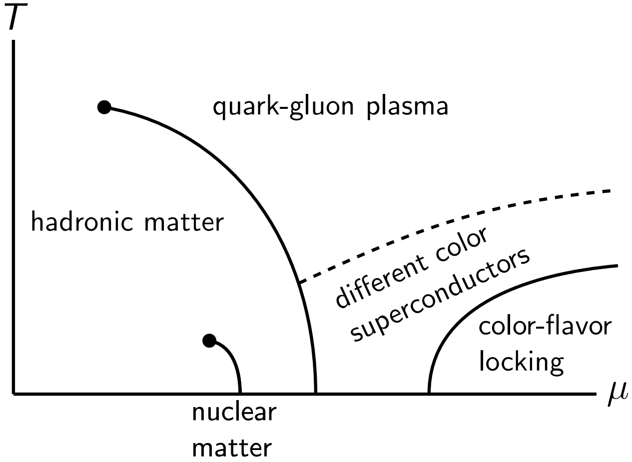


T
strange metal
antiferromagnet
pseudogap
normal metal
superconductor
μ

Motivation



T
quark-gluon plasma
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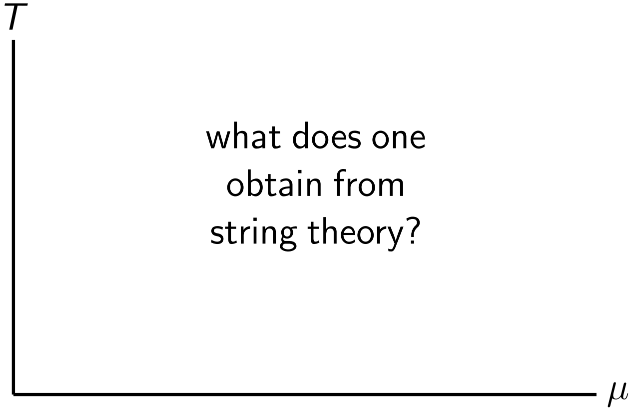
Motivation



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Some words about the setup

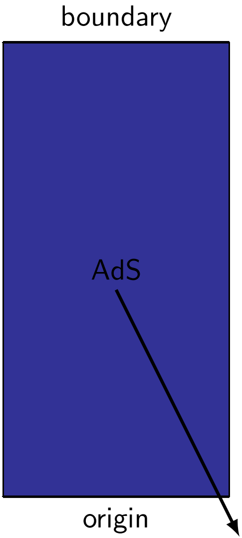
- I describe results from top-down models, where we extremize type IIB SUGRA, DBI and WZ actions
- D3/D7 system as the dual of, e.g. $\mathcal{N}=4$ SYM with charged matter in the fundamental
- I work in the Veneziano limit and D7-branes are smeared, but I won't go into details of this, only

$$1 \ll N_f \ll N_c^{1/3}$$

Qualitative description of the solution [1101.3560]

$$
\begin{aligned}
L = e^{-2\phi} & \left[R * 1 - \frac{1}{2} H \wedge * H - \frac{1}{2} \mathrm{d}\phi \wedge * \mathrm{d}\phi \right] \\
& - \frac{1}{2} F_1 \wedge * F_1 - \frac{1}{2} F_3 \wedge * F_3 - \frac{1}{4} F_5 \wedge * F_5 \\
& - \frac{1}{2} C_4 \wedge H \wedge F_3 \\
& - \frac{N_f}{N_c} \lambda \, e^{-\phi} \sqrt{-|G + \mathrm{d}A + B|} \\
& + \frac{N_f}{N_c} \lambda \, e^{\mathrm{d}A + B} \left[C_8 - C_6 + C_4 - C_2 \right]
\end{aligned}
$$

Qualitative description of the solution



$$L = e^{-2\phi}\left[R * 1 - \frac{1}{2}H \wedge *H - \frac{1}{2}\mathrm{d}\phi \wedge *\mathrm{d}\phi\right]$$
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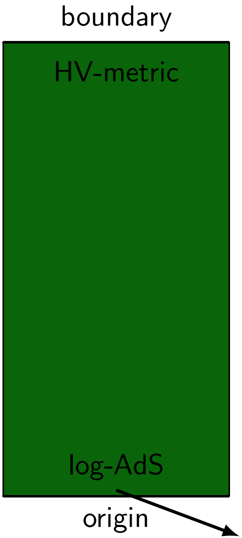
$$\mathrm{d}s^2 = -r^2\mathrm{d}t^2 + r^2\mathrm{d}\vec{x}^2 + r^{-2}\mathrm{d}r^2$$

Qualitative description of the solution [hep-th/0612118][1611.05808]



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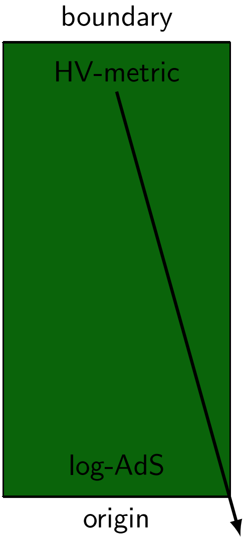
$$\mathrm{d}s^2 = \log r^{1/3} \left(-r^2 \mathrm{d}t^2 + r^2 \mathrm{d}\vec{x}^2\right) + r^{-2} \mathrm{d}r^2$$

Qualitative description of the solution [1611.05808]



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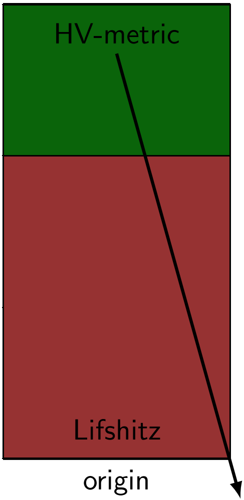
$$\mathrm{d}s^2 = r^{-7/3}\left(-r^2 \mathrm{d}t^2 + r^2 \mathrm{d}\vec{x}^2 + r^{-2}\mathrm{d}r^2\right)$$

Qualitative description of the solution [1707.06989]



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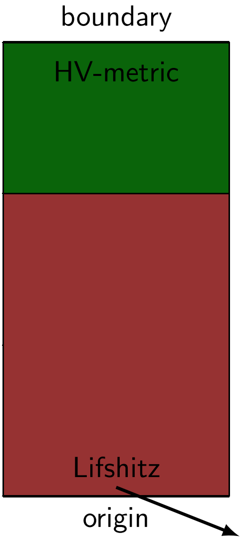

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$$\mathrm{d}s^2 = -r^{14} \mathrm{d}t^2 + r^2 \mathrm{d}\vec{x}^2 + r^{-2} \mathrm{d}r^2$$

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Main idea behind the holographic CSC mechanism

- The gauge group is encoded geometrically by number of D3-branes

$$S_{D3} = -N_c \int \sqrt{-g}\, \mathrm{d}t \mathrm{d}^3 x + N_c \int_{t,\vec{x}} C_4$$

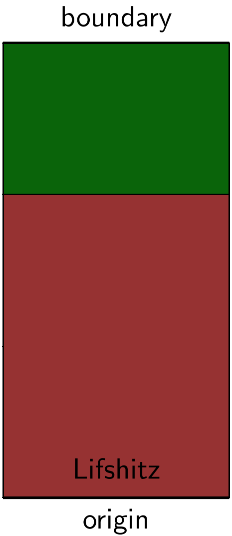
- And D7-branes also carry D3-brane charge!

$$S_{D7} \supset \frac{N_f}{8\pi^2} \int_{t,\vec{x},r,S^3} C_4 \wedge F \wedge F = N_f \int_{t,\vec{x}} C_4 \wedge \left(\frac{1}{8\pi^2} \int_{r,S^3} F \wedge F \right)$$

- If the appropriate F is turned on then we vary the rank of the gauge group

$$N_c \to N_c + N_f\, \psi$$

Instability towards color superconduction work in progress



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$$A = A_t(r) \mathrm{d}t$$

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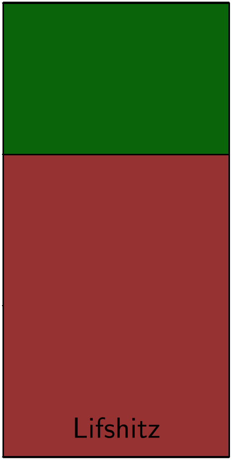

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$$A = A_t(r)\mathrm{d}t + \Psi(r)\, w^3(\theta s)$$

Instability towards color superconduction work in progress

- The BF bound in Lifshitz is

$$m^2 \geq -\frac{(p+z-\theta)^2}{4} = -25$$

- The new field has mass below the BF bound, so it needs to condense to avoid dynamic instability

- Backreaction of the mode in the supergravity fields affects the Gauss law for the D3-branes

$$\int_{S^5} F_5 \sim N_c - \frac{1}{2} N_f \Psi(r)^2$$

the color branes are separated: ~~$SU(N)$~~. Since color symmetry is broken we have *color superconductivity*

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Conclusions

- We have identified a IR phase of cold YM theories with charge density, given in the gravity side by a Lifshitz metric
- The IR is dynamically unstable towards condensation of a field dual to $\mathcal{O}^I \sim Q^\dagger \, \sigma^I \, Q$
- Condensation of the dual scalar field gives rise to a *color superconductor* phase

Thank you