Holographic Description of the QCD Phase Diagram & Out of Equilibrium Dynamics

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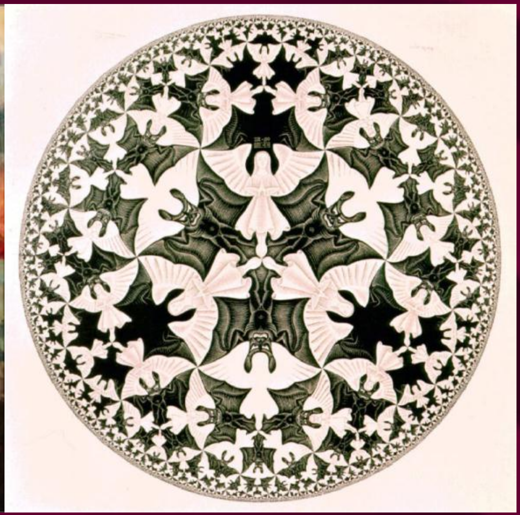


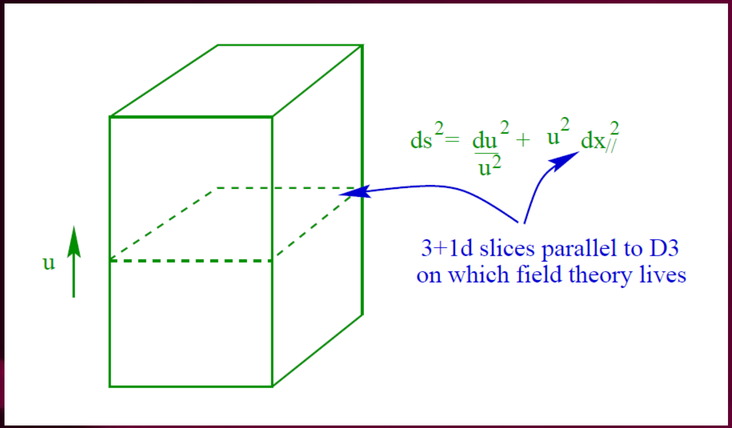
Keun-Young Kim

Maria Magou

Astrid Gebauer

Kolymbari, June 2012

Gauge Gravity Duality



String theory has provided a new way to study gauge theory

We treat RG scale as a space-time direction

The conformal symmetry of classical gauge theory is realized through AdS_5

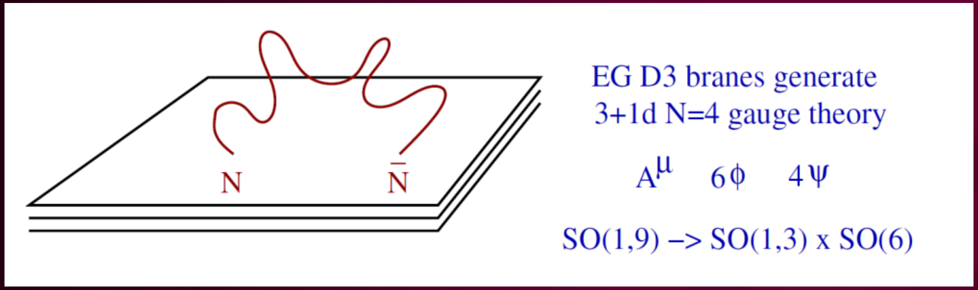
Gauge invariant operators and sources are represented by fields in the bulk

Dilatations

$$\begin{aligned} x &\rightarrow e^{\phi} x \\ A^{\mu} &\rightarrow e^{-\phi} A^{\mu} \\ u &\rightarrow e^{-\phi} u \end{aligned}$$

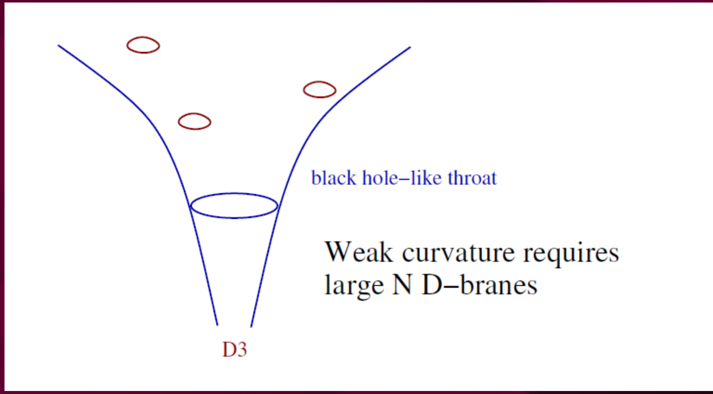
N=4 SYM

is the most controlled example base on Maldacena's inspired guess



Large N_c strongly coupled limit

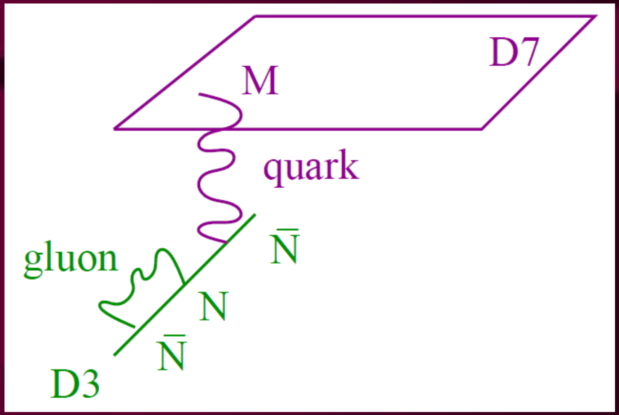
IIB strings on AdS_5 x S^5



A conformal quantum theory

Such Correspondences are much more general both in a top down and bottom up sense though

Add Quarks

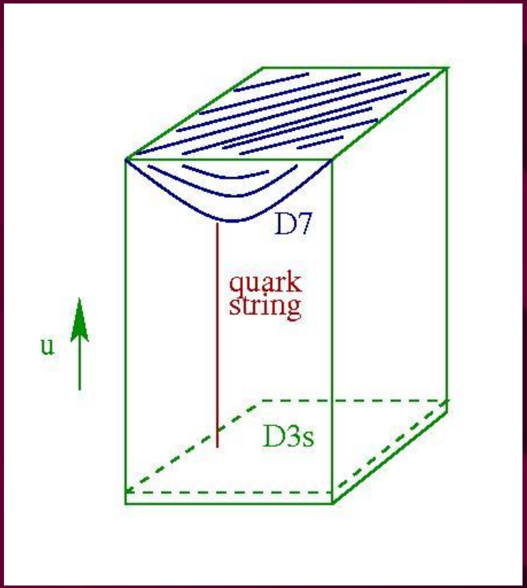


Add field in the bulk that describes

$\bar{q}\, q \qquad\qquad m_q$

The AdS/CFT dictionnary relates these to constants of integration in EoM

What action to take?



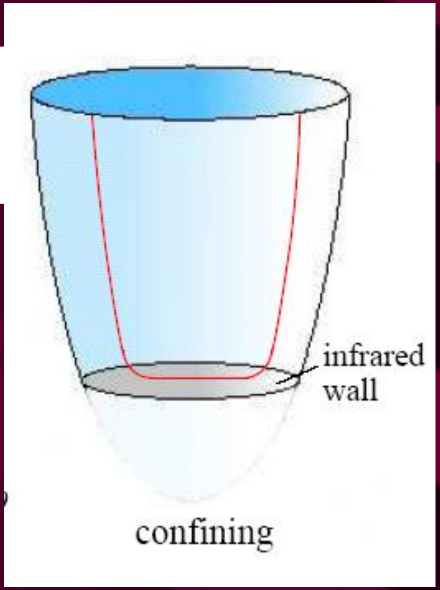
We minimize the area of the D7 in the geometry of the D3s ($N_f \ll N_c$)

Add Confinement and Chiral Symmetry Breaking

We can add in a field that corresponds to a running coupling

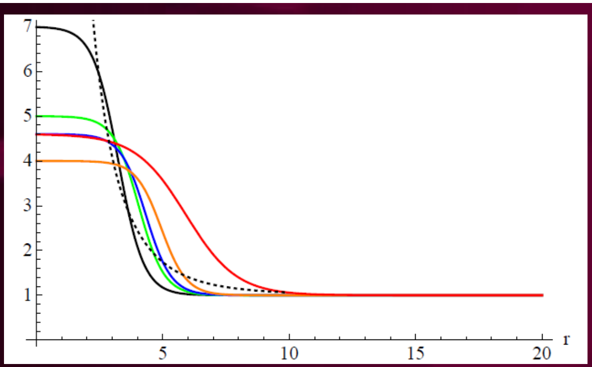
Top down – introduce a B field

$$e^{\Phi} = \sqrt{1 + \frac{B^2}{(\rho^2 + L^2)^2}}$$



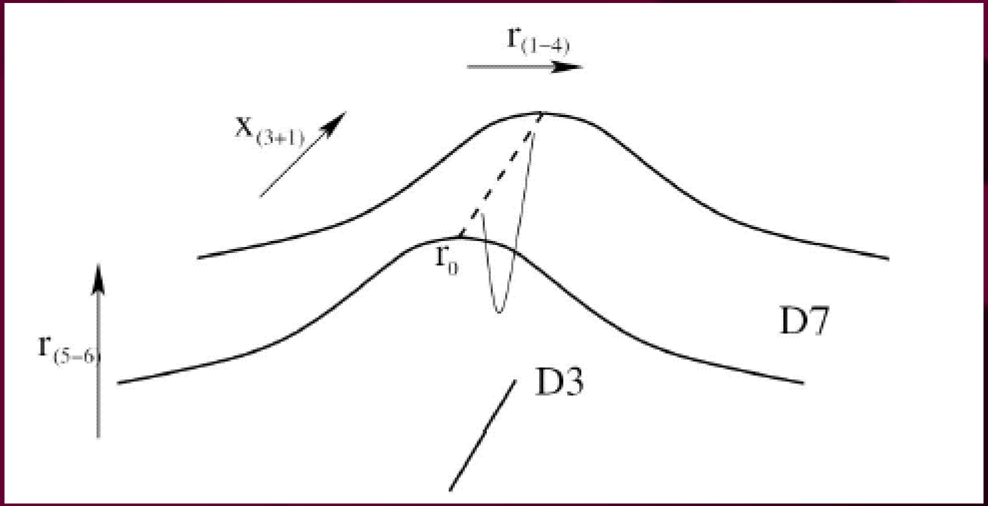
Or phenomenologically

$$e^{\Phi} = g^2_{\rm YM}(r^2) = g^2_{\rm UV}\Big(A + 1 - A\tanh\left[\Gamma(r - \lambda)\right]\Big)$$



The dilaton interpolates between QCD like case and “walking” dynamics (black is B field induced chiral symmetry breaking)

●is the scale of the problem..
A is height
☝ is width

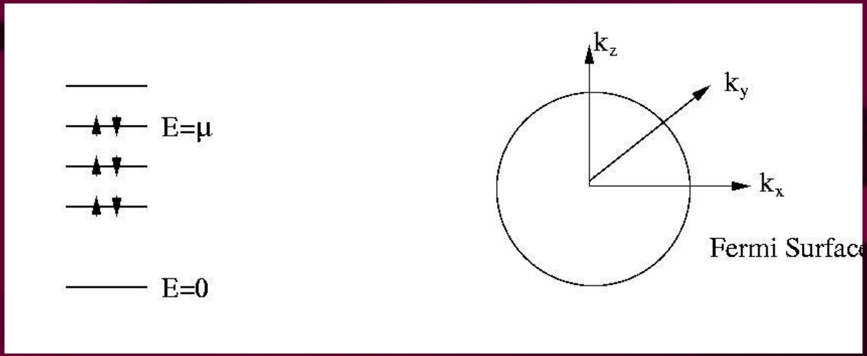


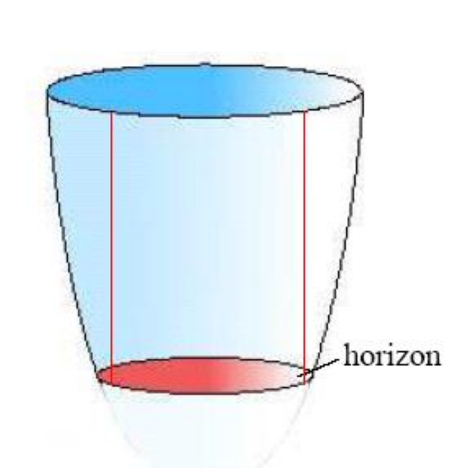
Add Temperature and Density

$$ds^2 = \frac{r^2}{R^2}(-f dt^2 + d\vec{x}^2) + \frac{R^2}{r^2 f} dr^2 + R^2 d\Omega_5^2$$

where $R^4 = 4\pi g_s N \alpha'^2$ and

$$f := 1 - \frac{r_H^4}{r^4}\,, \qquad r_H := \pi R^2 T\,.$$





Quarks are screened by plasma

A black hole "Hawking radiates at temperature T and heats up the gauge theory"

We can think of ❍ as a background vev for the temporal component of the photon…

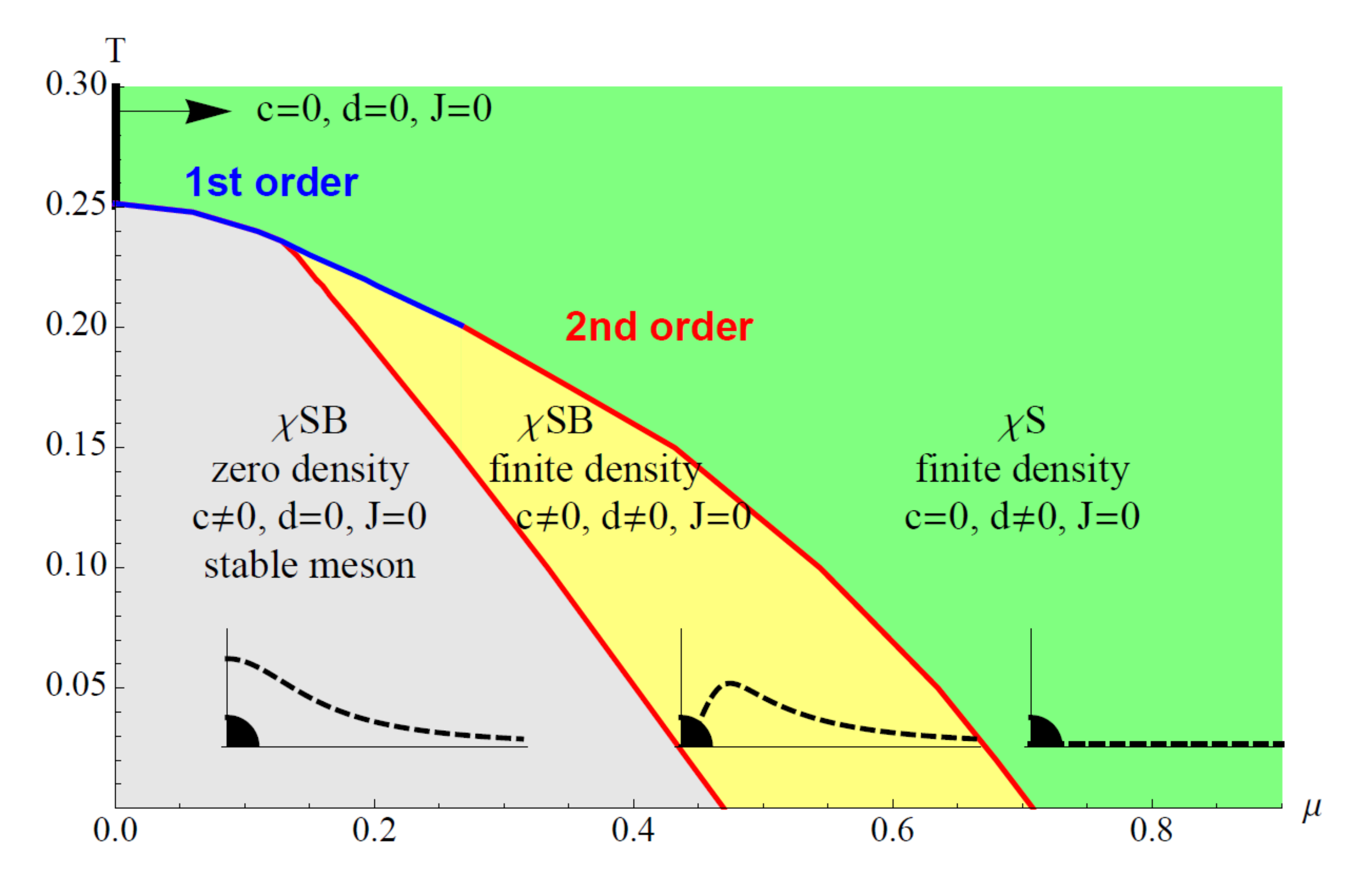
$$\bar{\psi} i(-iA^t \gamma_0)\psi \quad \rightarrow \quad \bar{\psi}\mu\gamma_0\psi$$

We add a new field to give

$$A^0 \simeq \mu + \frac{d}{\rho^3} + \ldots$$

The action is proscribed in top down models (D7 world-volume gauge field)

Phase Diagram for B Field Theory, m=0



JHEP 1003:132,2010.
e-Print: **arXiv:1002.1885** [hep-th]

More Phase Diagrams

NE, K-Y K, Gebauer, Magou

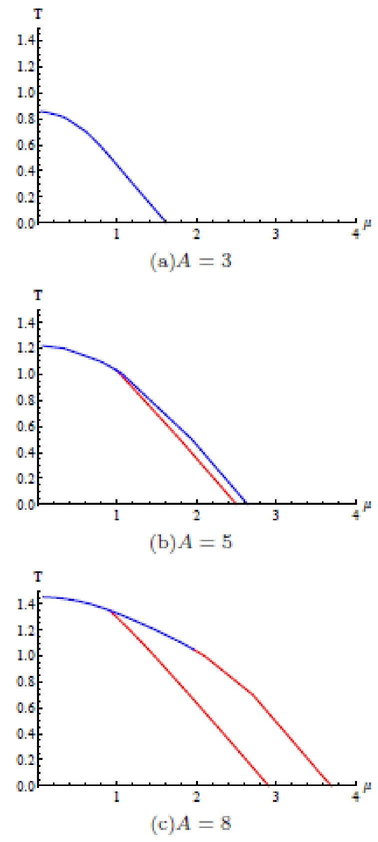
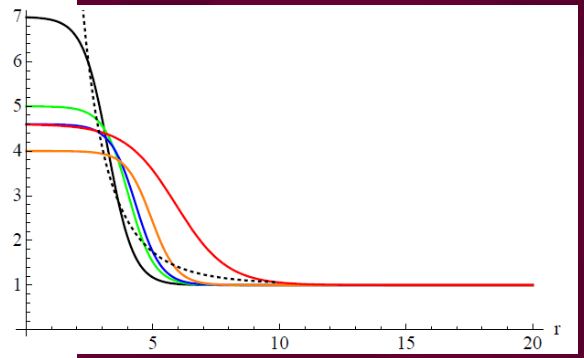


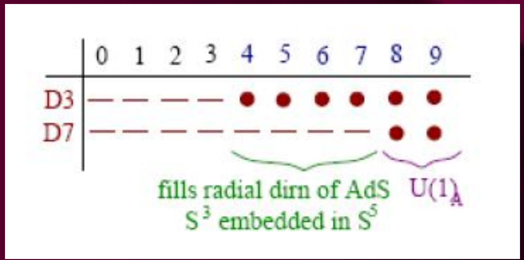
FIG. 6: Plots for three possible phase diagrams for the choices $A = 3, 5, 8$. Large (small) A gives second (first) order transition at low T. $\Gamma = 1, \lambda = 1.7$.



Walking encourages first order transition

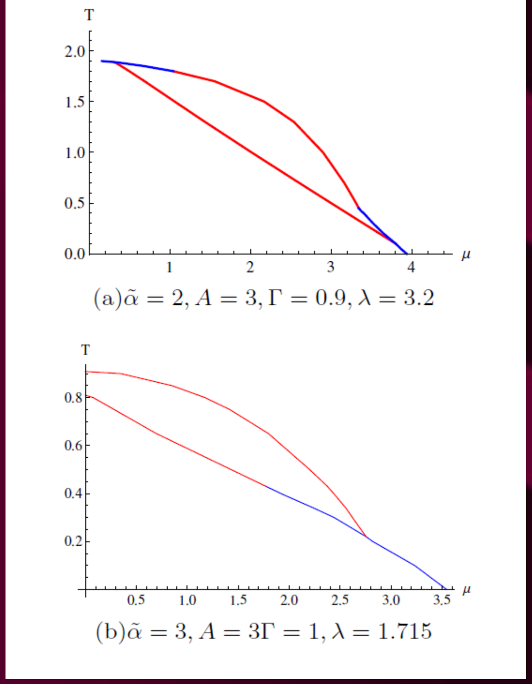
QCD-like phase diagrams…

Breaking the ❐-L symmetry



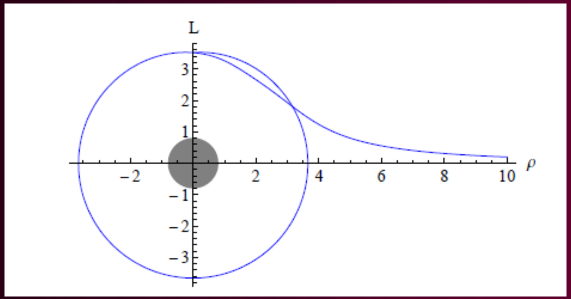
$$g_t = \frac{(w^4 - w_H^4)^2}{w^4(w^4 + w_H^4)}, \qquad g_x = \frac{w^4 + w_H^4}{w^4}$$

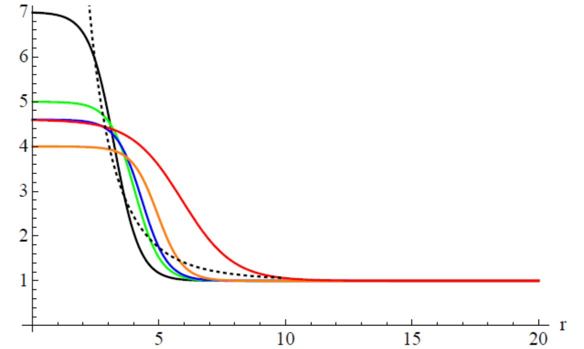
$$w^4 \rightarrow \rho^2 + \frac{1}{\tilde{\alpha}} L^2$$

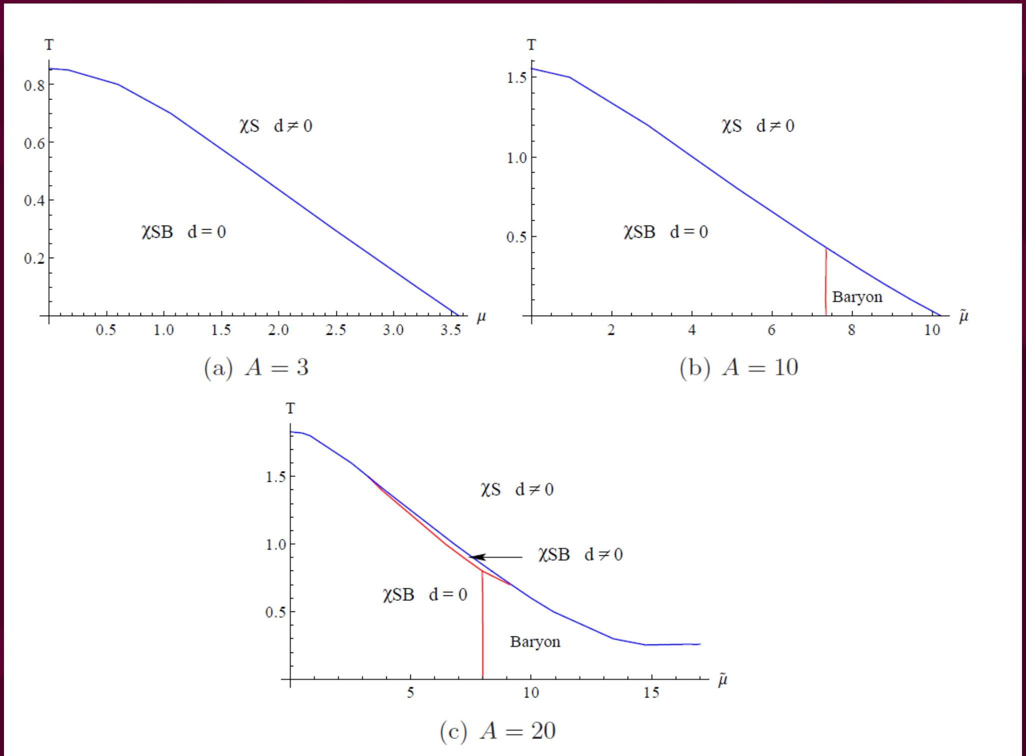


Baryonic Phase

Linked D7/D5 systems describe a baryonic density







Out of Equilibrium Dynamics

Chiral Transition in Janik's Cooling Geometry

With Ingo Kirsch, Tigran Kalaydzhyan (DESY)

The black hole grows/shrinks changing the effective potential…

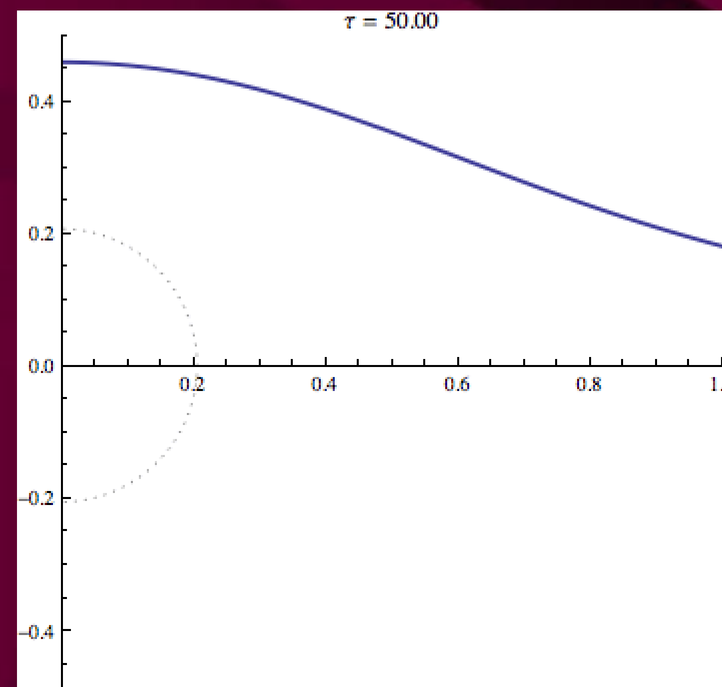
$$ds^2 = \frac{r^2}{R^2}\left(-e^{a(\tau,r)}d\tau^2 + e^{b(\tau,r)}\tau^2 dy^2 + e^{c(\tau,r)}dx_\perp^2\right) + \frac{R^2}{r^2}\left(d\rho^2 + \rho^2 d\Omega_3^2 + dL^2 + L^2 d\phi^2\right)$$

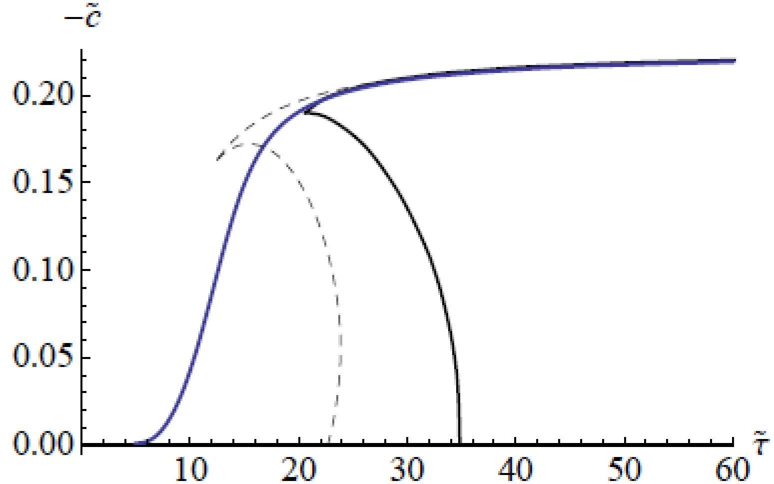
$$a(\tau,z) = \ln\left(\frac{(1-v^4/3)^2}{1+v^4/3}\right) + 2\eta_0 \frac{(9+v^4)v^4}{9-v^8}\left[\frac{1}{(\varepsilon_0^{3/8}\tau)^{2/3}}\right] + \mathcal{O}\left[\frac{1}{\tau^{4/3}}\right],$$

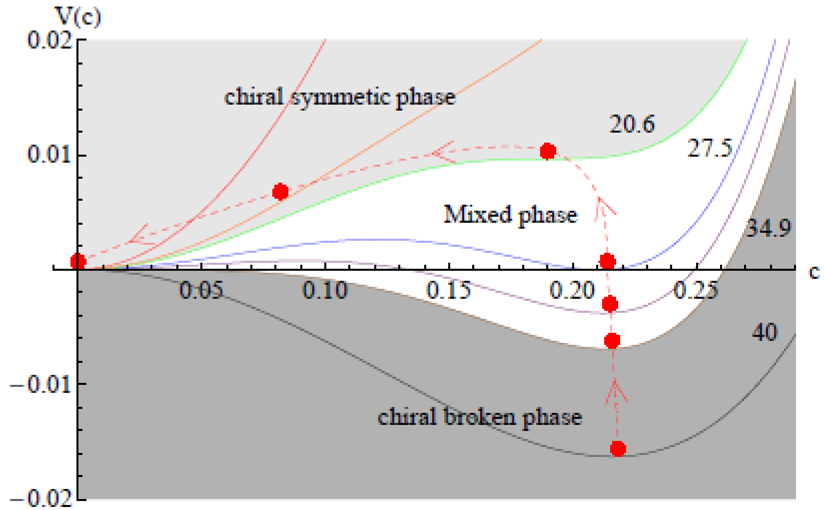
$$b(\tau,z) = \ln(1+v^4/3) + \left(-2\eta_0\frac{v^4}{3+v^4} + 2\eta_0 \ln\frac{3-v^4}{3+v^4}\right)\left[\frac{1}{(\varepsilon_0^{3/8}\tau)^{2/3}}\right] + \mathcal{O}\left[\frac{1}{\tau^{4/3}}\right],$$

$$b(\tau,z) = \ln(1+v^4/3) + \left(-2\eta_0\frac{v^4}{3+v^4} - \eta_0 \ln\frac{3-v^4}{3+v^4}\right)\left[\frac{1}{(\varepsilon_0^{3/8}\tau)^{2/3}}\right] + \mathcal{O}\left[\frac{1}{\tau^{4/3}}\right],$$

D7 dynamics with B field…

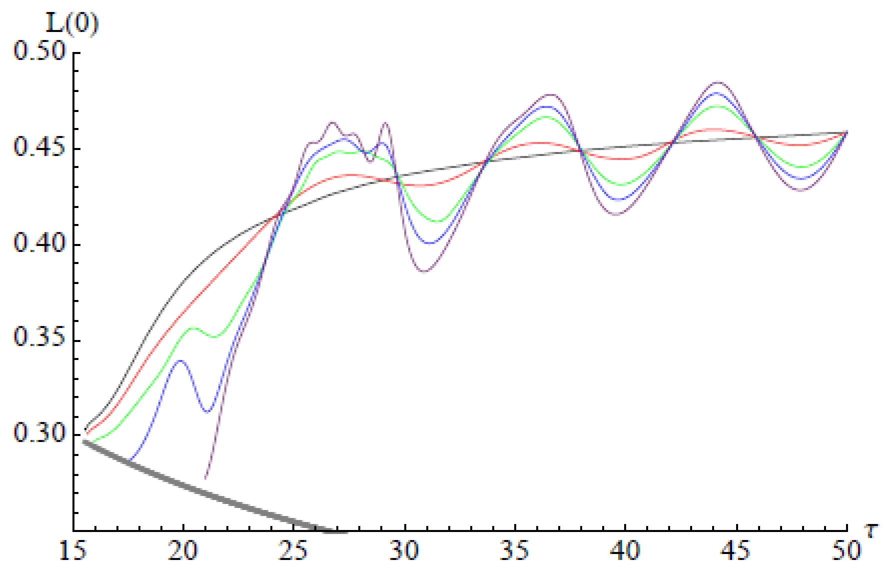






Equilibrium vs PDE solutions…

Bubble formation…



Conclusion

Strongly coupled phase diagrams with rich structure
arXiv:1002.1885 [hep-th], arXiv:1109.2633 [hep-th], arXiv:1204.5640 [hep-th]

Out of equilibrium dynamics arXiv:1011.2519 [hep-th]