D3/D7 plasmas at finite density and temperature

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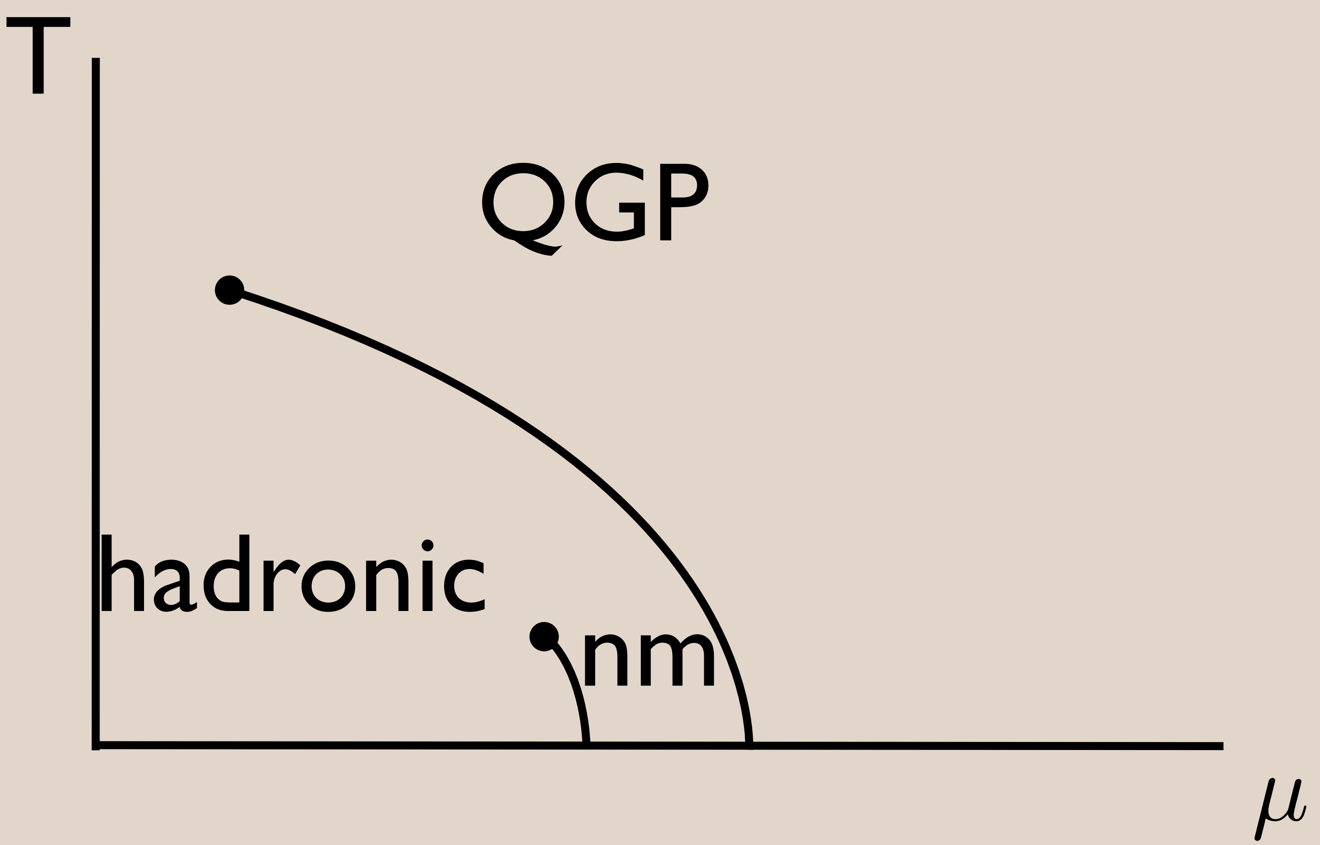
Paris, 12th June 2013

- Motivation
- AdS/CFT
- A bit about my setup
- Some physical results
- Limitations
- Prospects

Motivation

- QCD has a rich phase diagram at finite T and μ
- Details only known in certain regimes
- Strong coupling physics dominates an important region
- Use holography to study systems at finite μ and possibly low T



Cartoon of QCD phase diagram

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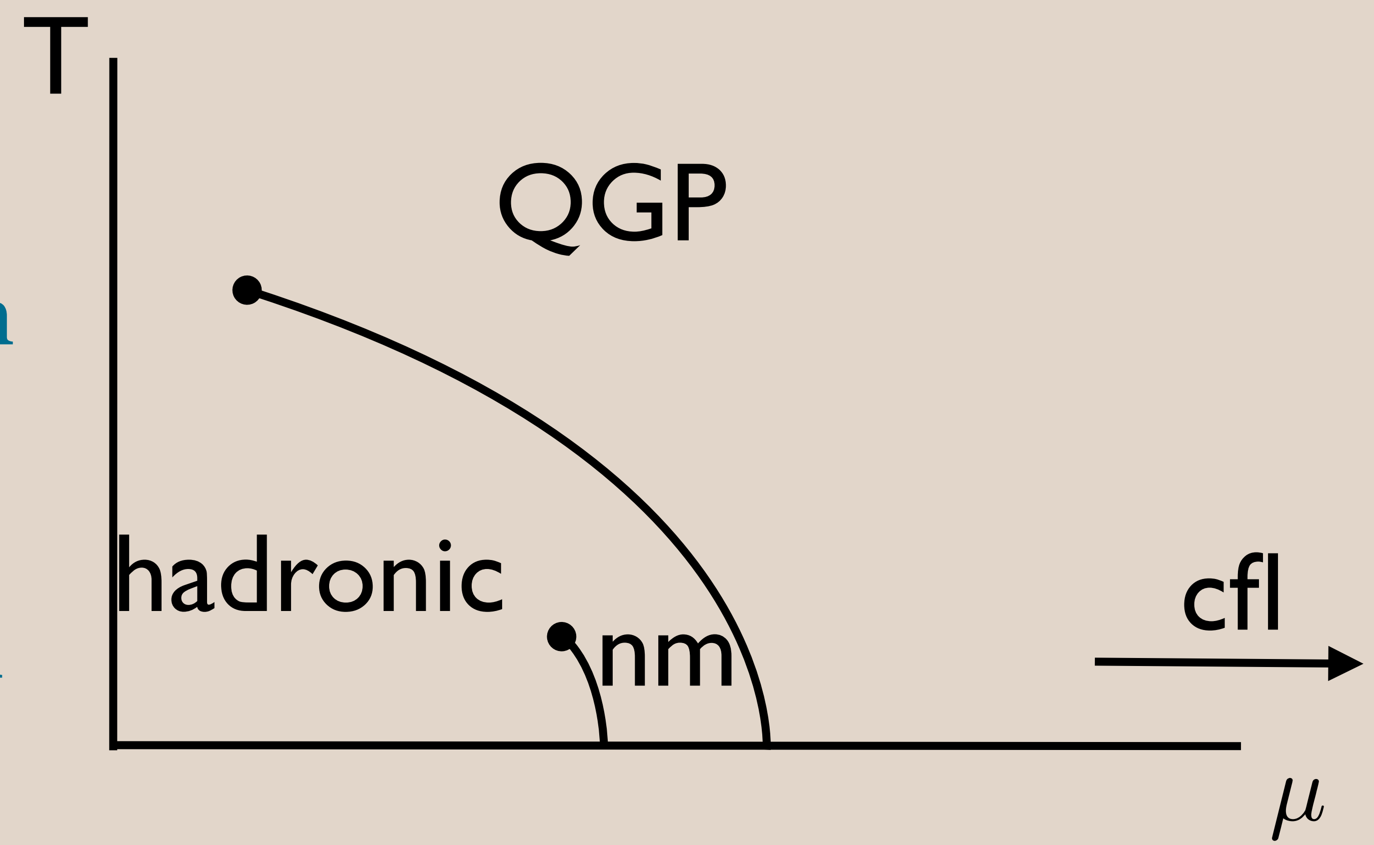

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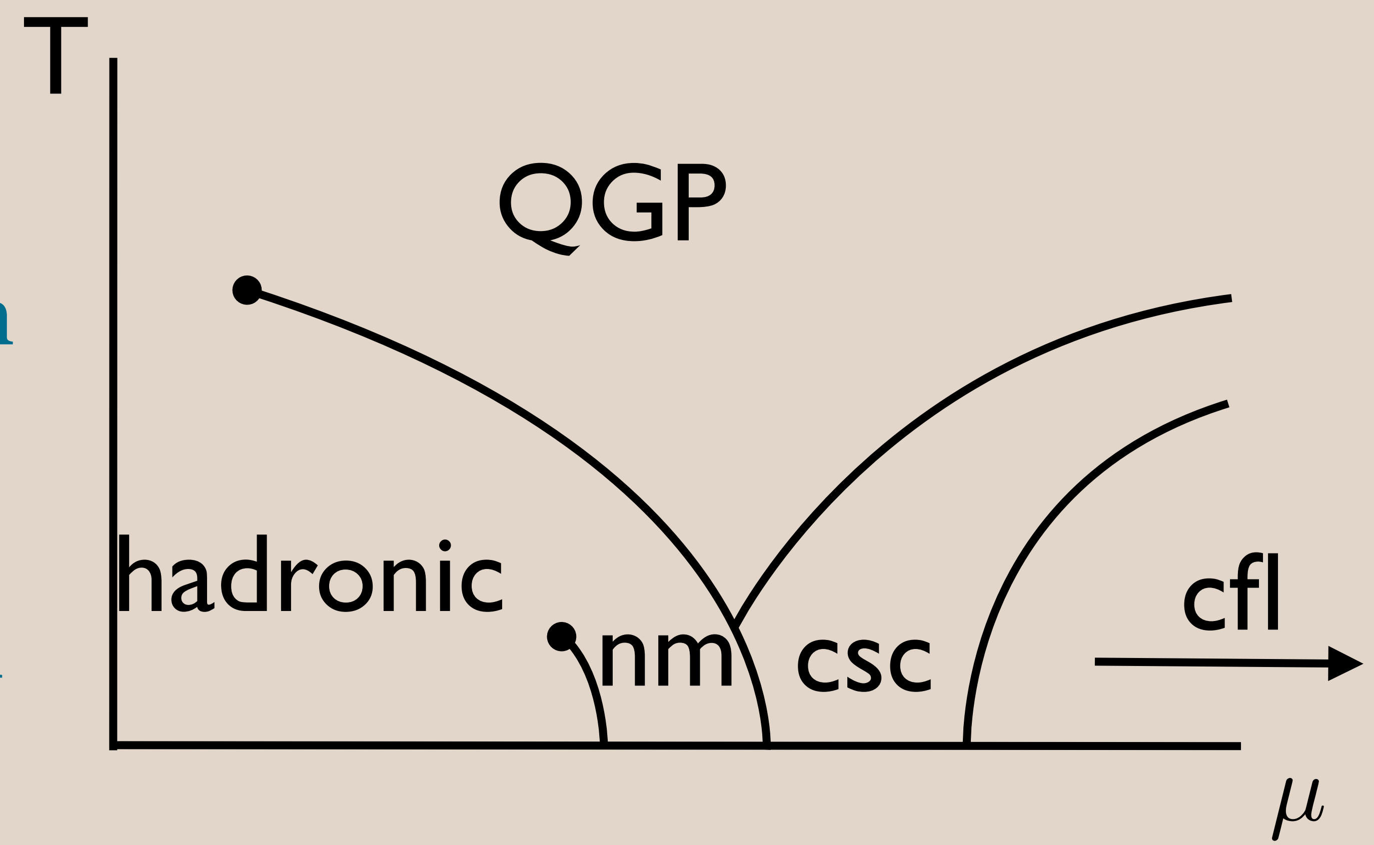

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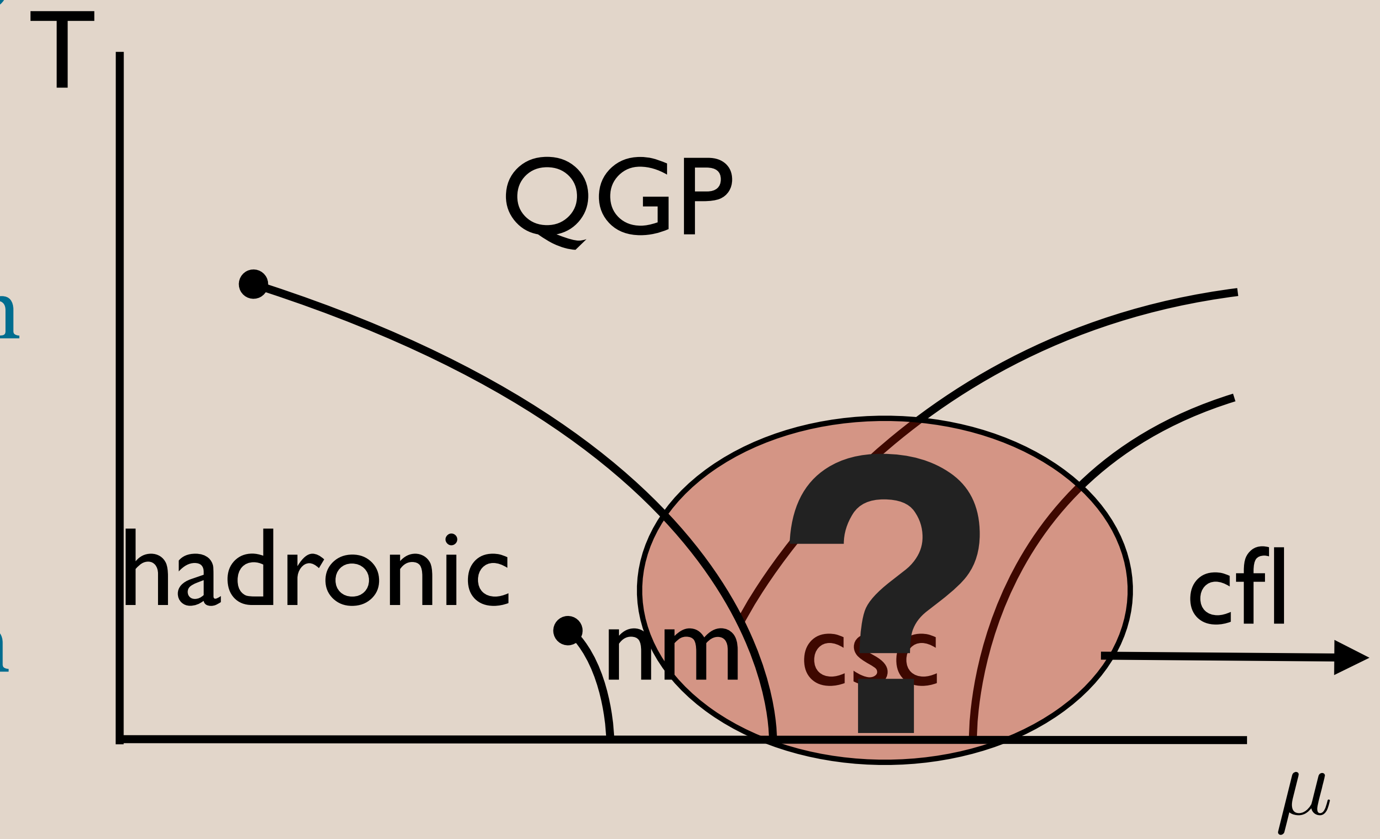


Cartoon of QCD phase diagram

AdS/CFT

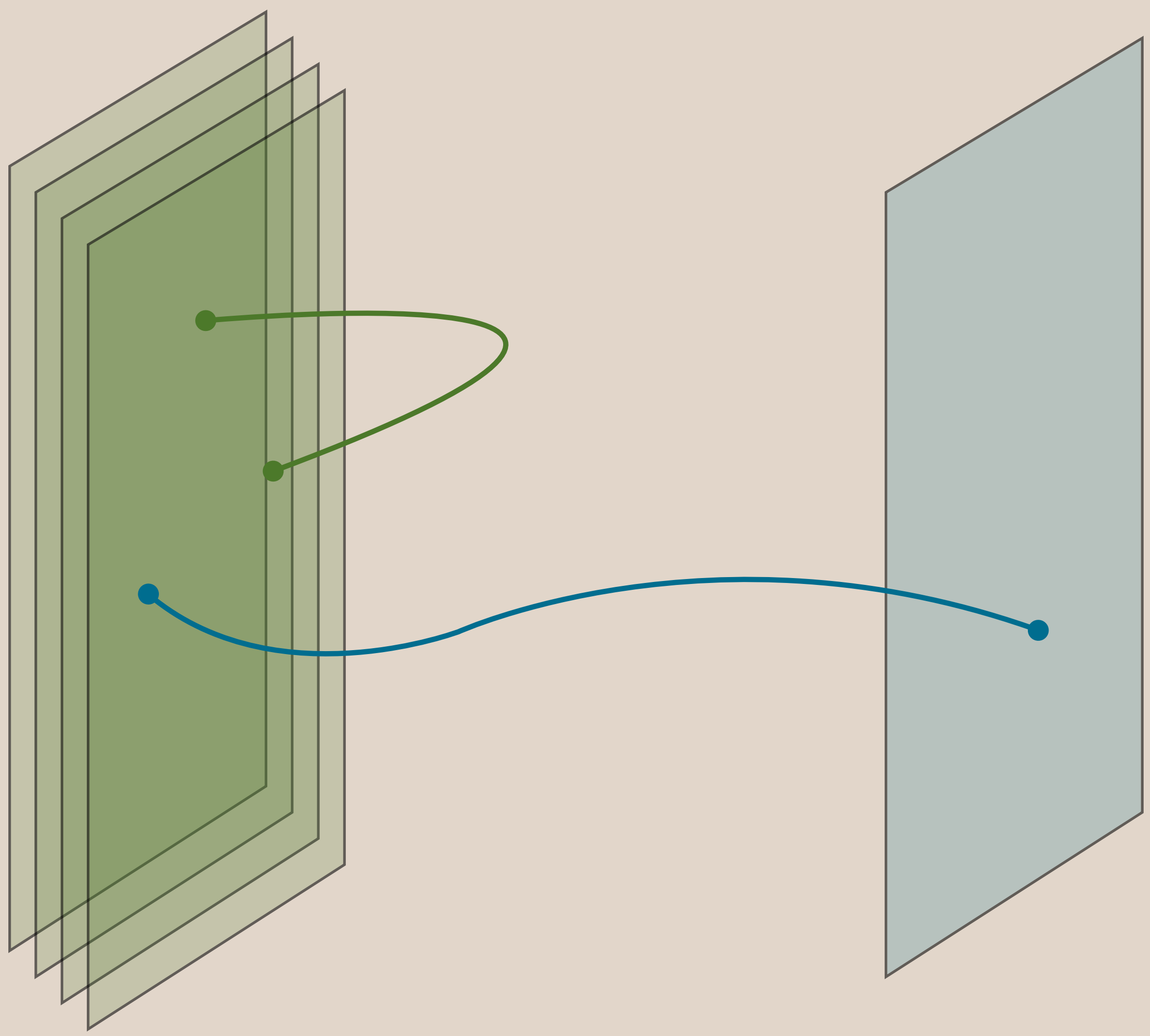
- Conjectured duality between field theories and gravity theories
- Weak/strong duality: extract strong coupling effects from classical gravity
- Fields in gravity provide sources and vevs of the FT operators
- Provides geometric interpretation of field theory features or viceversa

AdS/CFT

- No known dual for QCD
- Bottom-up vs. top-down models

Nc>>1	
‘t Hooft vs Veneziano	
unknown field theory	field theory explicit
tunable parameters	fixed phenomenology

Setup



- Take N_c D3-branes, this is $SU(N_c)$ SYM

$$N_c \to \infty$$

- Strings represent fields in the adjoint
- Add Nf D7-branes
- New strings give fields in the fundamental

Karch, Katz hep-th/0205236

Setup

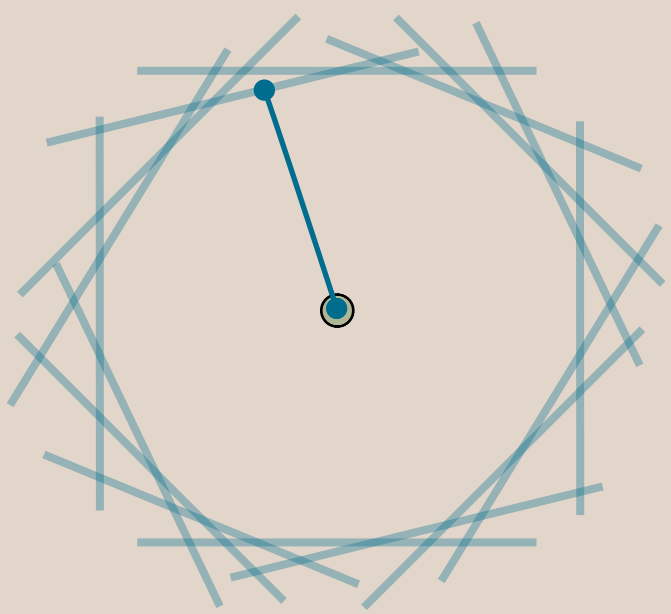
Bigazzi, Casero, Cotrone, Kiritsis, Paredes hep-th/0505140

see review arXiv:1002.1088 for references

ϵ

$$S = \frac{1}{2\kappa_{10}^2}\left(\int \mathcal{L}_{IIB} - \#\lambda\frac{N_f}{N_c}\int \mathcal{L}_{D7}\right)$$

I will consider the Veneziano limit



$$\mathcal{L}_{D7} \sim \sqrt{-P[G]}\,\delta^2(D7) + WZ \longrightarrow \mathcal{L}_{D7} \sim \sqrt{-P[G]}\,\Omega_2 + WZ$$

Basic dictionary

- Finite temperature = black hole
- RG flow = radial dependence
- Running coupling = non-trivial dilaton
- In SUSY case the beta function is exact

$$\beta \propto \lambda^2 \frac{N_f}{N_c} \qquad \Rightarrow \qquad g_{YM}^2(Q^2) = \frac{16\pi^2}{N_f \log \frac{\Lambda_L^2}{Q^2}}$$

- there is a Landau pole, the sugra solution will also have this pathology (dilaton diverges)

Basic dictionary

- Finite baryon chemical potential = DBI action for the flavor branes

$$\mathcal{L}_{D7} \sim \sqrt{-P[G]}\,\Omega_2 \to \sqrt{-P[G]+F}\,\Omega_2$$

- Analytic solutions at finite T and μ available perturbatively in the backreaction parameter $\epsilon \sim \lambda \frac{N_f}{N_c}$

Bigazzi, Cotrone, Mas, Paredes, Ramallo, JT arXiv:0909.2865

Bigazzi, Cotrone, Mas, Mayerson, JT arXiv:1101.3560

Bigazzi, Cotrone, JT arXiv:1304.4802

Effective action

- Not so complicate effective action describing the system

$$
\begin{aligned}
S = \frac{1}{2\kappa_5^2}\int \Bigg[&(R-V)\star 1 - \frac{40}{3} df\wedge\star df - 20 dw\wedge\star dw - \frac{1}{2} d\Phi\wedge\star d\Phi \\
&- \frac{1}{2} e^{\Phi+4f+4w}\left(dC_0 - 2\sqrt{2}C_1\right)\wedge\star\left(dC_0 - 2\sqrt{2}C_1\right) \\
-\frac{1}{2} e^{\Phi-\frac{4}{3}f-8w}&\left(dC_1 - Q_7\mathcal{F}_2\right)\wedge\star\left(dC_1 - Q_7\mathcal{F}_2\right) - \frac{1}{2} e^{\Phi-\frac{20}{3}f} dC_2\wedge\star dC_2 \\
&- 4Q_7 e^{\Phi+\frac{16}{3}f+2w}\sqrt{-\left|g + e^{-\frac{\Phi}{2}-\frac{10}{3}}\mathcal{F}_2\right|}\,\Bigg] ,
\end{aligned}
$$

Landau pole

- Consider two scales associated to r_1 and r_2

  and using

$$\epsilon_1 \propto \lambda_1 \frac{N_f}{N_c} = 4\pi g_S N_f e^{\Phi(r_1)}$$

- Then under a change of scale, from the solution, we have

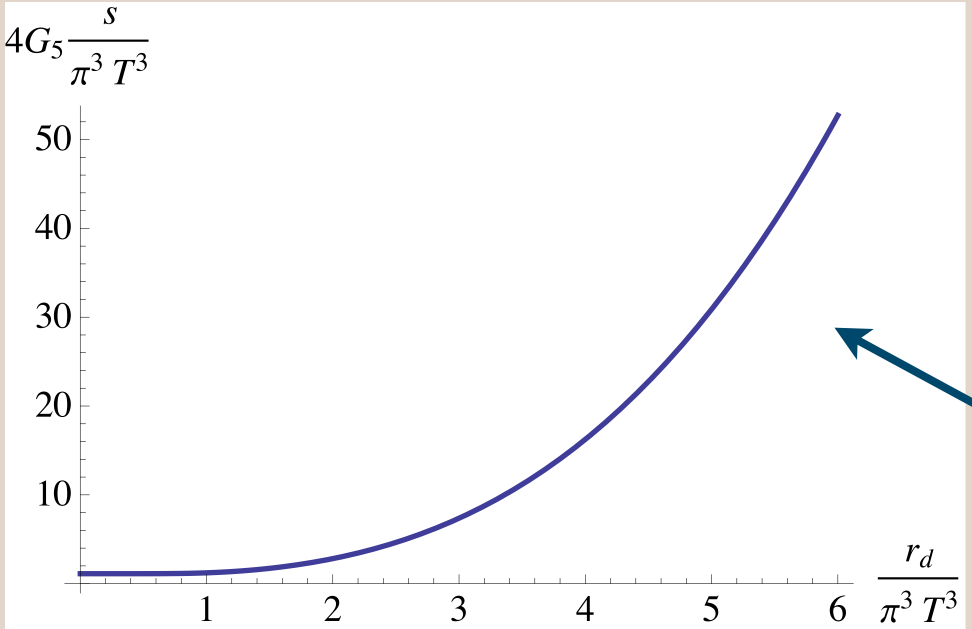
$$\epsilon_1 = \epsilon_2 e^{\Phi_2 - \Phi_1} = \epsilon_2 + \epsilon_2^2 \boxed{\log \frac{r_1}{r_2}} + \cdots$$

Effective IR dynamics

- In the charged case we have at 1st order

$$S_{eff} = \frac{1}{2\kappa_5^2}\int d^5x \left(R + 12 - 4\epsilon_h\sqrt{1+\frac{F^2}{2}}\right)$$

Pal arXiv:1209.3559



Bigazzi, Cotrone, JT arXiv:1304.4802

$$s = \frac{\pi^3}{4G_5}T^3\left(1 - \frac{\epsilon_h}{2} + \epsilon_h\sqrt{1+\frac{r_d^6}{\pi^3 T^3}}\right)$$

Physical consequences

- Flavor corrections to transport coefficients

Bigazzi, Cotrone, JT arXiv:0912.3256

- Increased loss of energy of probes through the plasma

Magana, Mas, Mazzanti, JT arXiv:1205.6176

- drag force
- jet quenching

- Strange optical properties

a la Amariti, Forcella, Mariotti, Policastro arXiv:1006.5714

Fluctuations

- Charged system expected to be unstable
  - Charged scalars in the field theory: BE cond.
  - Charged fermions (chiral density wave)
  - CS-like couplings trigger instabilities

  Ammon, Erdmenger, Lin, Müller, O'Bannon, Shock arXiv:1108.1798
- All bosonic worldvolume fields studied in probe approximation
- We can include supergravity couplings

  Bigazzi, Cotrone, JT arXiv:1304.4802
- However we can NOT go to zero temperature and everything remains stable

Extremality

- Problem: it is a perturbation on top of a neutral black hole solution

  - Inner horizon at radius $\mathcal{O}(\epsilon)$
  - Increasing baryon density requires the whole resumation of the solution

- Physically: energy density of D7-branes always dominates in the IR

  - This is true also in the 't Hooft limit and in particular the problem holds for probe calculations

Hartnoll, Polchinski, Silverstein, Tong arXiv:0912.1061

Summary & conclusions

- We studied SYM theory with fundamental matter with symmetry $U(1)^{N_f}$
- Reasonable analytic control to include phenomenological features
- Possibility to study plasma observables perturbatively in N_f/N_c
- IR physics obtained from simpler system
- A different approach to study extremality in the charged black hole must be taken

Extremality again

ongoing work with David Mateos and Prem Kumar

- In the ∞ massive quarks limit a charged solution at zero temperature found

Kumar arXiv:1206.5140

$$ds^2 = -\rho^{14} dt^2 + \rho^2 d\vec{x}^2 + \rho^{-2} d\rho^2$$

- This solution (plus more) is found in a particular limit of our system!

- Apparent instability due to an instanton mode in the D7-branes

similar to Ammon, Jensen, Kim, Laia, O'Bannon arXiv:1208.3197

- D3-branes pulled out by strings? A color-superconducting phase?

Thank you