Bubbles from Dark Confinement with Holography

Nicklas Ramberg

nramberg@uni-mainz.de

Collaborators

Enrico Morgante & Pedro Schwaller

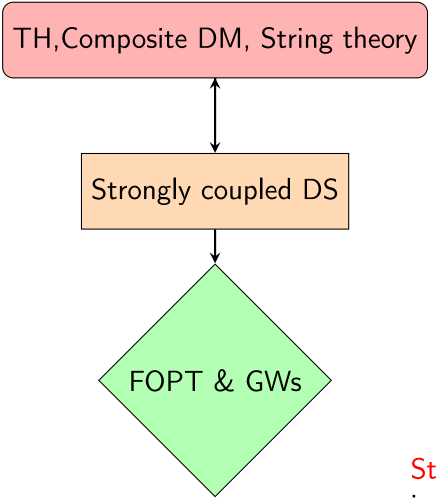
2210.11821

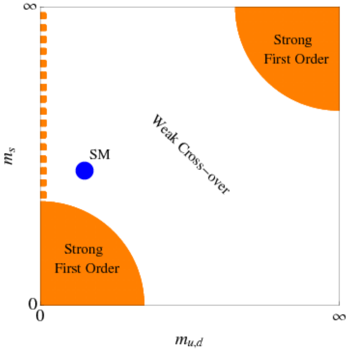
230?.?????

How Fast Does The Bubble Grow

May 15, 2023

SU(N) Yang-Mills

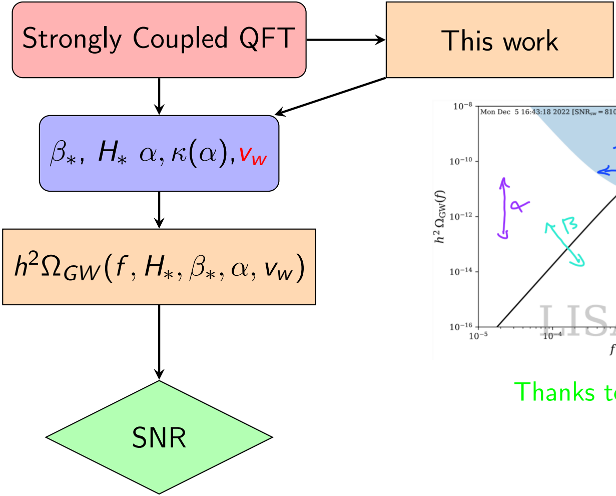


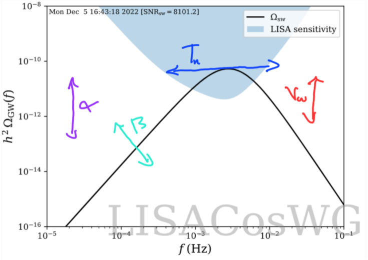


Schwaller 2015

Strategy: Employ AdS/CFT in a Bottom up perspective

- LISA PT working group 2019





Thanks to PTPlot

Improved Holographic QCD

5D ED gravity in AdS $\rightarrow$ 4D Large N_c Yang-Mills Kiritsis, Nitti,Gursoy 2007

$$\mathcal{S}_5 = -M_p^3 N_c^2 \int d^5x\sqrt{g}\left(R - \frac{4}{3}(\partial\Phi)^2 + V(\Phi)\right) + 2M_p^3 \int_{\partial\mathcal{M}} d^4x\sqrt{h}\mathcal{K},$$

- $V(\Phi)$ dilaton potential
- 5-D coordinate r $\Longleftrightarrow$ RG scale
- Dilaton $\lambda = e^{\Phi}$ $\Longleftrightarrow$ t'Hooft coupling $\lambda_t = N_c g_{YM}^2$
- AdS-BH/Thermal AdS $\Longleftrightarrow$ Phases of SU(N_c)

The potential $V(\lambda)$ and It's Parameters

UV Asymptotics

$$V(\lambda) = \frac{12}{\ell^2}(1 + v_0\lambda + v_1\lambda^2 + \ldots)$$

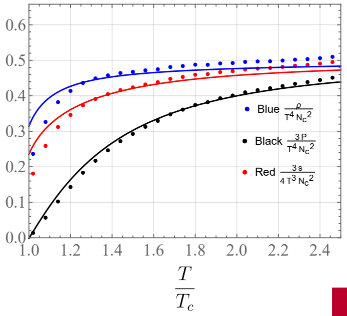
IR Asymptotics

$$V(\lambda) \sim \lambda^{\frac{4}{3}} (\log(\lambda))^{\frac{1}{2}}$$

V_0 V_2 YM beta function 2-loops

V_1, V_3 Phenomenological parameters

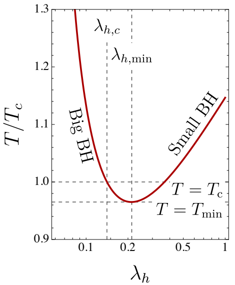
V_1 Free gas asymptotics, V_3 Latent heat

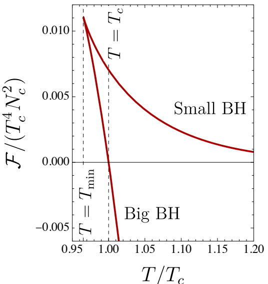


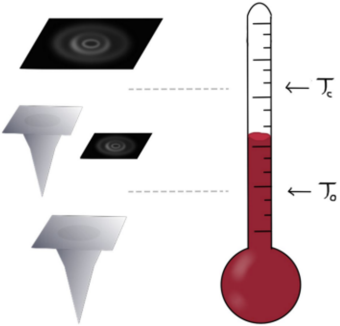
$V1 = 170, \qquad V3 = 14.$

$$V(\lambda) = \frac{12}{\ell^2}\left(1 + V_0\lambda + V_1\lambda^{\frac{4}{3}}(\log[1 + V_2\lambda^{\frac{4}{3}} + V_3\lambda^2]^{\frac{1}{2}})\right)$$

Finite T Solutions

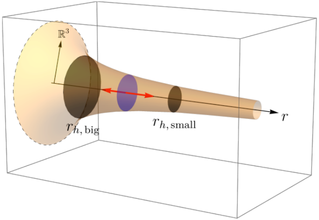




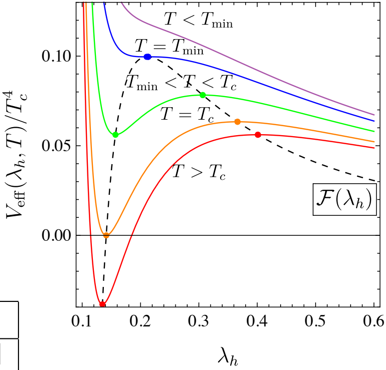


Dewolfe 2013

Confinement (HP) Phase Transition & Effective Action I



Thanks To Enrico!



Big BH	Small BH	TG
Deconfined	Saddle Point	Confined

$$V_{\mathrm{eff}}(\lambda_h, T) = \mathcal{F}(\lambda_h) - 4\pi M_p^3 N_c^2 b(\lambda_h)^3 \left(1 - \frac{T_h}{T}\right) .$$

JG|U

Confinement (HP) Phase Transition & Effective Action II

Kinetic Term Normalization

$$c\frac{N_c^2}{16\pi^2}$$

We vary $c \to \frac{1}{3} - 3$, Moderate dependence on GW spectrum

Thermal Tunneling effective action $\mathcal{O}(3)$ symmetric bounce

$$\mathcal{S}_{eff} = \frac{4\pi}{T}\int d\rho\,\rho^2\left[c\frac{N_c^2}{16\pi^2}(\partial_\rho\lambda_h(\rho))^2 + V_{\rm eff}(\lambda_h(\rho), T)\right]$$

Nucleation Rate for Thermal Tunneling

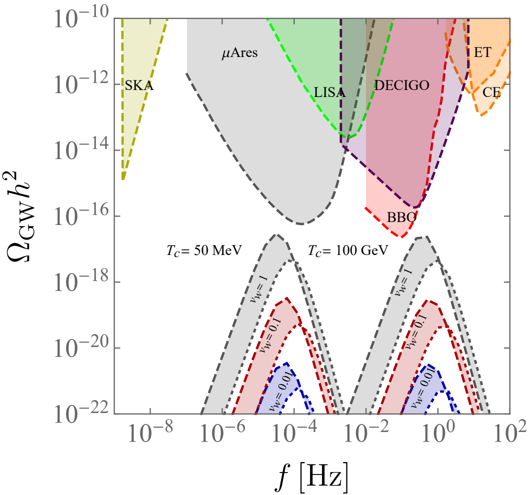
$$\Gamma = T^4\left(\frac{\mathcal{S}_B}{2\pi}\right)^{3/2} e^{-\mathcal{S}_B}\,.$$

Percolation: $\mathcal{P}(true) \simeq \mathcal{P}(false)$ (End of PT! GW Emission)

	α	$\beta/H\,(v_w = 1)$	$\beta/H\,(0.1)$	$\beta/H\,(0.01)$
$T_c = 50\,\mathrm{MeV}$	0.343	9.0×10^4	8.6×10^4	8.2×10^4
$100\,\mathrm{GeV}$	0.343	6.8×10^4	6.4×10^4	6.1×10^4

JG|U

Gravitational Wave Spectra SU(3) "The Money Plot"



GW spectra for SU(3) at different critical temperatures

How to estimate v_w at strong coupling?

Reference	2103.09827	2202.10503, 2205.06274	2104.12817
Theory	SU(N) YM	Strong Gauge theory	SUSY SU(N) YM
Approach	Pheno	Bottom-up	Top-Down
Supercooling	minimal	minor/moderate	moderate/large
v_w	$v_w \sim 10^{-4}$	$v_w \sim \mathcal{O}(0.01 - 0.3)$	$v_w \sim \mathcal{O}(0.01 - 1)$

Employ steady state approach like Bigazzi 2104.12817

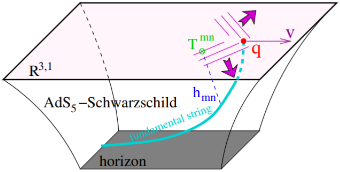
$$\Delta P_{fric}^{tot} = 0 = \frac{F_{fric}}{A} + \Delta P_{bubble}$$

Consider the drag force on an external quark stationary moving in the plasma as the plasma friction $F_{fric} \sim F_{drag}$.

Trailing String & Drag-Force

Moving external quark in Plasma
$\Longleftrightarrow$ String whose boundary endpoint follow quark

Momentum flow along string
$\Longleftrightarrow$ Drag force on quark moving in plasma.



From Dewolfe 2013

$$F_{drag} = \frac{dp_1}{dt} = \pi_\xi = -\frac{v e^{2A(\lambda_s)} \lambda_s^{\frac{4}{3}}}{2\pi \ell_s^2}$$

$$\Delta P_{fric}^{tot} = 0 = \frac{F_{drag}}{A} + P_f(T_{boost}) - P_f(T_{perc})$$

T_{boost} is the 2-D worldsheet BH temperature generated by the induced metric.

Preliminary Results!

Access to the pressures in deconfined phase from the lattice fit.

Finally for the wall velocity we obtain so far

$$v_w = 0.07 \pm 0.03$$

Further insights based on phenomenological arguments regarding this velocity computation are under consideration, $F_{fric} \sim N_c^2 F_{drag}$, reflected gluons of bubble wall ...

Take Home message: Quantitative predictions of GWs at strong coupling are at our grasp thanks to clever use of tools, even for not perfect CFTs!